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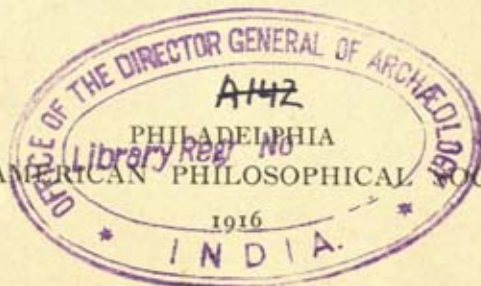
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PROCEEDINGS
OF THE
AMERICAN PHILOSOPHICAL SOCIETY
HELD AT PHILADELPHIA
FOR PROMOTING USEFUL KNOWLEDGE

THE GEOLOGY OF PARAHYBA AND RIO GRANDE DO
NORTE, BRAZIL.

PLATES I-IV.

BY RALPH H. SOPER.

(*Read December 3, 1915.*)

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INTRODUCTORY.

The data for the following paper was gathered in a series of three expeditions made into the states of Parahyba and Rio Grande do Norte. The actual time consumed in collecting the material dated from the latter part of March, 1912, until the middle of February, 1913. The writer was sent into the field by the Brazilian

government to investigate the practicability of drilling wells and procuring water throughout the two states mentioned above. The notes on the geology were made in connection with and as a part of that work.

The topography of Parahyba and Rio Grande do Norte is not one of strong contrasts. There are no great mountain ranges and no large rivers. In fact there is not a single stream in either state that can be depended upon to flow during the entire year. The climate, for the most part, is hot and dry—a somewhat unexpected phenomenon for a region in 5 degrees south latitude. The rainfall is irregular, being copious one year while the next it may fail entirely. Moreover, it is seldom distributed over a considerable time or area, but is more likely to fall locally in a torrent, and then after a dry period of weeks, there is another torrent.

The states of Parahyba and Rio Grande do Norte have comparatively few inhabitants and their struggle for life during the last 200 years forms one of the epics of South America. Driven from their homes time after time by thirst and hunger, they have always returned and are still in the sertão,¹ enduring untold privations and waiting with infinite patience the arrival of happier times.

The topography of the accompanying map is based on the "Mappa dos Estados do Ceará, Rio Grande do Norte e Parahyba," by H. E. Williams and R. Crandall. With the exception of the coastal sediments south of Natal, which are shown according to J. C. Branner, the geology is the writer's own work. The region covered is an extensive one and the work was done by means of horseback meanders, a pedometer, pocket compass, aneroid, and hand level. In general, however, the geological areas shown are accurate within the map scale used.

The writer wishes to acknowledge his indebtedness to Professors J. C. Branner, Orville A. Derby, and to Dr. M. Arrojado Lisboa, for valuable help and suggestions. Among the papers consulted, two were found to be of especial value, namely, "The Geology of the Northeast Coast of Brazil," by J. C. Branner and "Geographia, Geologia, Supprimento d'Agua, Transportes, e Açudagem," by Roderic Crandall.

¹ "Sertão" is the word used in northeastern Brazil to denote the back country or the interior.

TOPOGRAPHY.

The states of Parahyba and Rio Grande do Norte form three general topographic divisions. The first is a zone of low coastal sediments of Cretaceous and Tertiary age. The second is a great plateau which rises from the western edge of the coastal plain and sweeps clear across the two states thus embracing more than two thirds of their area. The third division consists of a series of high serras which rise abruptly from the surrounding plain, and whose summits are often remarkably flat.

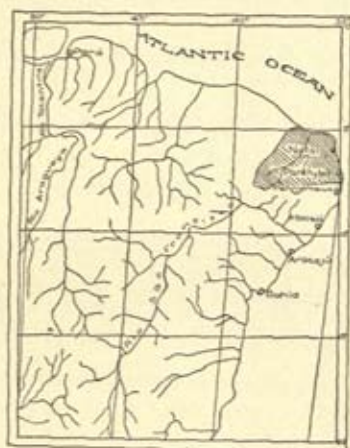


FIG. 1. Index map.

The coastal belt may be further divided into that part which immediately adjoins the sea, marked by shifting sand-hills, low swampy areas overgrown with mangroves and by general poverty in vegetation; and second, into the higher sedimentary land, the limestone and sandstone areas, usually covered by a dense caatinga² forest. This latter region includes the Chapadas of Apody and São Sebastião, rich fertile regions almost uninhabited. The topography of this sedimentary region, as a whole, has a low relief, the only prominent features being the line of sand dunes which stretches along the coast (especially prominent in the vicinity of Natal), and

² Caatinga is a Brazilian term for a low, brushy forest.

the low, plateau-like chapadas mentioned above. In the eastern part of Parahyba the coastal sediments are scarred by short streams which have narrow, fertile valleys and steep banks, where erosion has cut deeply into the soft beds.

The plateau region can be described briefly as a great rolling plain of hard, crystalline rock, covered irregularly by a growth of caatinga, dense or sparse according to the character and degree of decomposition of the underlying rocks. It covers by far the greater portion of the two states and ranges from an elevation of 100 meters near the contact with the sediments, to 300 meters further inland. It is in this region, locally known as the "alto sertão," that drought is most severely felt.

Rising abruptly from this undulating plateau and attaining a height of from 500 to 600 meters, is a series of serras which form the only relief in the monotonous topography. Most marked of these serras is the Planalto de Borborema with a mean elevation of about 500 meters, which reaches from the southern portion of Rio Grande do Norte, clear across the central portion of Parahyba and forms a part of the boundary of that state with Pernambuco. In the vicinity of Campina Grande it has a width of more than 100 kilometers but narrows to the north of there. The Serras Canabava, Jabitaca, Baixa Verde and Teixeira form a part of the boundary referred to above.

From the Serra Teixeira there is a low line of mountains stretching away to the eastern part of Ceará. Some of the larger ones are the Serra Mellado, Serra Catharina and the Serra do Vital. There are several more, smaller and without names, significant only in that they form a part of a general structural feature. The Serra Santa Catharina is the most important of the mountains named and reaches a height of about 650 meters. To the north of this mountain line, beginning near Souza and stretching in a north-east direction almost to Catolé do Rocha, is a long mountain called the Serra Commissario. I did not cross this serra, but from a distance it appeared to be a series of small buttes rather than one great mountain.

Still further north of the Serra Commissario, and forming

a part of the division line between the states of Rio Grande do Norte and Parahyba, is another mountain range. Beginning with the Serras S. Miguel, Luiz Gomes, and Serra Padre, which mark the meeting point of the three states, Parahyba, Rio Grande do Norte, and Ceará, and stretching away in an easterly direction are the Serras Negra, Barriguda, Furada, Patú, and other minor ones. Between the end of this line and the northeast point of the Serra Borborema, here called Serra Mattos, lies the Serra João do Valle.

All of the mountains or tablelands thus far mentioned are more or less similarly constructed, that is, they arise abruptly from the surrounding plain, are usually flat-topped and are composed entirely of crystalline rocks; some of them have a core of granite. Other than the more important serras whose names have been given there are many small isolated peaks or serrotes of granite and gneiss which rise irregularly and sharply out of a rolling, caatinga-covered plain.

There is one other type of mountain found in these states illustrated by the Serras Martins, Porto Alegre, and João do Valle. The Serra João do Valle I did not visit but saw from a distance. Mr. Roderic Crandall³ describes it as being of the same structure as the others named. These serras represent an unusual phenomenon. They rise abruptly from the plain of Rio Grande do Norte, to an elevation of about 700 meters and their summits are remarkably flat-topped. The bulk of the mountains are composed of crystalline rock, nearly all schist with some gneiss, as is also the surrounding country. But their summits are capped with sandstone, about 50 meters thick. These three mountains, in so far as I have been able to determine, are peculiar in this respect.

DRAINAGE.

The drainage everywhere in Parahyba and Rio Grande do Norte flows to the east or northeast; in other words it takes the shortest course to the sea. Along the southern border of Parahyba the watershed marks the boundary between that state and Pernambuco.

³ Roderic Crandall, "Geographia, geologia, supprimento d'agua, transportes, e açudagem," page 6, Rio de Janeiro, 1910.

Of the various streams the rivers Apody (or Mossoró), Assú, Ceará Mirim, and Parahyba, are the most important. The Rio Jaguaribe in the southern part of Ceará might also be included, for the territory drained by it is physically the same and has passed through the same history as the adjoining region in Rio Grande do Norte. Not a single stream in the entire territory under consideration is perennial. The reason for this is partly the scarcity and irregularity of the rainfall, partly the hard, impervious nature of the rocks, and partly the hot, dry climate.

GEOLOGY.

For the purposes of the present study the geological formations represented in the states of Parahyba and Rio Grande do Norte may be classed in two groups as follows: first, the ancient (Archean to early Paleozoic) rocks which have been called the Brazilian complex by Dr. Branner;⁴ second, the comparatively modern (Mesozoic to Recent) rocks which we call the sedimentary series.

The Brazilian complex consists of crystalline rocks (mainly gneiss) and schists disposed in inclined beds which are quite thickly threaded with dikes and bosses of various eruptives, among which granites predominate.

The rocks of the second group consist mainly of sandstones, limestones, and incoherent sand and clay deposits (including dunes), all of them disposed in horizontal or approximately horizontal beds.

In general terms the two groups as shown on the accompanying map are evenly distributed. With the exception of a comparatively narrow strip along the coast and a few isolated spots in the interior, the whole of the two states is made up of the crystalline rocks. No attempt at a systematic classification of this division will be made here. I have not had the time nor the opportunity to do more than to observe some of the broader features. However, to intelligently understand the geologic conditions in this region, it is necessary to know that the rocks of the Brazilian complex cover practically all of the interior; and that the more recent sedimentary beds along the coast have been formed by the deposition of sedi-

⁴ "Geologia elementar," 2d ed., pp. 286-289. Rio de Janeiro, 1915.

ments derived from this original land mass. It is necessary also, to know that these rocks are not homogeneous but that they are hard here and soft and decomposed a few feet away; that they have been crushed, metamorphosed and recrystallized to a remarkable extent, and that one may find a hard granite "serrote" standing out in the midst of an area of soft schist. Everywhere the rocks are cut by quartz veins which range from a few centimeters to half a meter in diameter and occasionally there are pegmatite veins.

Mr. Roderic Crandall in his paper entitled "Geographia Geologia, Supprimento d'Agua, Transportes e Açudagem" makes a further division which he calls the "Series Ceará." I have not made this distinction, but have included the rocks of the Ceará series under the more general head of the schists of the Brazilian complex. However, they have a few distinguishing characteristics which I shall give briefly. The Ceará series, where it is distinguishable, seems to be composed of acid rocks, usually of a light color. They contain more or less kaolin and clay and in some cases have a peculiar earthly appearance. On weathering off they do not weather into rounded boulders with smooth surfaces, but outcrop in jagged exposures and the boulders, large and small, have sharp edges—not rounded ones. The Ceará series usually presents a schistose appearance and in places according to Mr. Crandall, may contain lenses of hard, vitrified sandstone. In other places there are masses of limestone completely isolated in areas of schist. However, there does not seem to be any systematic separation of this series from the other rocks and it is often, if not usually, impossible to make any distinction at all. No attempt has been made by anyone to map them separately. Hence, although all of the schists are probably not strictly crystalline, I have included them with the crystalline rocks of the Brazilian complex.

In regard to the distribution of the granites, I have already said that they form the axes of some of the principal serras. Also, they are especially noticeable along the contact of the crystalline mass with the sediments. In such a vicinity the former usually takes the shape of rounded boulders and bosses of granite and gneiss. Small patches of granites, however, are found occasionally outcropping

throughout the crystalline areas of Parahyba and Rio Grande do Norte.

The sedimentary series, as previously indicated, may be separated into three divisions. First, there is a bed of rather coarse-grained and sometimes conglomeritic sandstone which directly overlies the crystalline rocks. In color it is usually brick-red but may also be yellow or white. The color is probably due to varying amounts of iron stain. The contact between this sandstone and the crystalline rocks was first seen where it crosses to the southeast side of the Rio Jaguaribe, a few kilometers to the south of Limoeiro. From there it passes close to the village Taboleiro d'Areia and continues to follow the general direction of the Chapada do Apody, but about 9 kilometers back to the southwest of the Chapada, until it reaches Passagem Funda. At this point the contact is 15 kilometers to the south. From here it continues to follow the direction of the escarpments of the Chapadas São Sebastião and Vacca Morta, always from 8 to 12 kilometers to the south of them. These last two named escarpments are in reality only a continuation of the scarp of the Chapada do Apody. At Assú the contact passes almost through the city and from there on to Natal it is very regular, always approach-nearer to the coast as we go south. It passes very close to the village Garapeba, and to the railway station Baixa Verde, passes just north of Taipú, south of Ceará Mirim, and is seen about 5 kilometers west of Macahyba. From this point south it is noted a few kilometers west of S. José, passes through Curimatú, goes close to Espirito Santo, and Pedra de Fogo. Thus the sandstone is exposed in a narrow strip from near Aracaty, at least to Natal and probably on down into the state of Pernambuco. A section at right angles to its length would show a consistent width of exposed area from 8 to 12 kilometers. The only reliable structure that I have seen in this rock was in the vicinity of Apody, along the escarpment of the Chapada do Apody, and near Assú, along the Lagoa Piató. In these places the sandstone beds dip from 3 to 8 degrees to the northeast or toward the sea. There are some good exposures near Garapeba also, but little structure is evident there. For the most part the exposed sandstone is seen on the surface as an incoherent, heavy, yellowish-

brown sand, with no hard rocks at all. No fossils have ever been found in this sandstone. The beds are at least 30 meters thick.

Directly overlying the sandstone is a bed of hard, fine-grained limestone which is usually of a grayish or yellowish color. It is exposed in a continuous strip from near Aracaty to Natal and is known to exist in several places between Natal and Parahyba. It is not unlikely that this strip of limestone continues on uninterrupted into the state of Pernambuco. As is shown on the accompanying map, the escarpment of Apody, beginning in the vicinity of União, follows a general southwest direction until it reaches a point about due west of Apody. There it swings sharply about and follows a northeast direction to Passagem Funda. At Passagem Funda the river Apody has cut squarely through the chapada and the east side of the river is known as the Chapada do São Sebastião while the west side retains the name of Apody. In reality the two low plateaux comprise a single physical feature. The escarpment of the Chapada do São Sebastião is a continuation of the scarp of the Chapada do Apody. This former makes a detour to the south and then follows a northeast direction to the village Rua da Palha. Here the same thing has happened as was noted at Passagem Funda. The Rio Upanema has cut through the Chapada do São Sebastião and the part of the serra which lies to the northeast of the river has become known as the Serra or Chapada da Vacca Morta. The escarpment of the Serra Vacca Morta trends a little to the northeast from Rua da Palha as far as the northern margin of the Lagoa Piató, and finally becomes lower and lower until about 6 kilometers east of the lagoa, it merges with the low hills that make up the topography of that region. The remarkable thing about this escarpment which varies from 30 to 100 meters in height, is that it marks the contact between the sandstone and the limestone. Everywhere along its entire length the base of the escarpment is sandstone while the top is limestone. The whole surfaces of the Chapadas of Apody, São Sebastião and Vacca Morta, are limestone. From the Lagoa Piató to Natal the contact between the sandstone and limestone has been only approximately located. It crosses the Rio Assú about 9 kilometers north of the city of that name and continues in a general easterly direction. Near the fazenda Sant'Antonio, 30 kilometers to

the southeast of Assú, the contact is exposed again. Thereafter it was found about 4 kilometers south of Baixa Verde (the village—not the railway station), and again a little to the north of the railway station—Itapassaróca. At Ceará Mirim the limestone is 31 meters below the surface (near the church), and it has been noted about 20 kilometers west of Natal, near Macahyba. South of Natal the writer has not explored the limestone, but Dr. J. C. Branner⁵ reports that it is found near São José, Goianinha, Pequiry and Parahyba. Hence it is probable that the same geologic relations exist to the south of Natal, as are known to exist to the north.

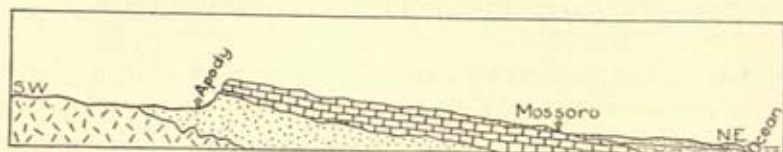


FIG. 2. Section across the Chapada do Apody.

The limestone exposed in the strip above mentioned has a varying width, which reaches its maximum in the vicinity of Mossoró. Here a cross section would show a width of at least 70 kilometers. At Assú probably 25 kilometers would cover it. From Baixa Verde a section east would show the limestone to be about 16 kilometers wide while in the vicinity of Natal it is probably less than 10 kilometers across.

The only place where the structure was clearly seen in the limestone was along the scarp of the Chapada do Apody and along the Rio Apody, from Passagem Funda to São Sebastião. There, rock dips toward the northeast; in places it is horizontal. At the fazenda Sussarana, 23 kilometers northeast of Apody, and again near the village São Sebastião, Mr. Crandall, in the paper previously referred to, reports that he observed the sandstone underlying the limestone. This means that in spite of the apparent seaward dip the beds are horizontal, or approximately so. Furthermore, a well has been drilled in Mossoró to a depth of 45 meters. The first 30 meters were in limestone and the last 15 in sand. Judging from this the

⁵ J. C. Branner, "Geology of the northeast coast of Brazil," *Bulletin of Geological Society of America*, Vol. XIII., pp. 93-95. Rochester, 1902.

same horizontal relation exists clear to Mossoró, for if the sandstone dipped uniformly seaward, even at an angle of one degree, it must in the 60 kilometers from Passagem Funda to Mossoró attain a considerably greater depth than 30 meters. The limestone has a thickness of between 30 to 50 meters. This estimate is based upon the exposures along the Rio Apody and upon two wells drilled, one in Mossoró above mentioned, and the other in Macáu. The well in Macáu showed the limestone to be 44 meters thick. The age of these limestones lies between the late Cretaceous and early Tertiary. Mr. Crandall⁶ reports fossils from them (these fossils are in the museum of the "Serviço Mineralógico" in Rio de Janeiro), and I have found a few.

Finally, overlying the limestones and extending on to the sea, is the third division of the sedimentary rocks, a more recent deposit, mostly sands and clays. The surface of this deposit is very sandy but when drilled into it is seen to contain a great deal of clay. The sand is calcareous in places. I have not seen any bedded rock between the limestone and the ocean but in some places there are patches of hard, sandstone boulders, often of a conglomeritic nature. The best exposures of these recent beds were seen during a trip from Lagoa dos Mattos to Areia Branca. From this first named place on to Mutomba, and again for two kilometers at the Morro do Thibáu, the sandstone is exposed in a bluff which varies in height from 15 to 20 meters. This rock usually has a belt of conglomerate at the base about 3 meters thick. Over this is a highly colored sandstone, rather hard and cemented with iron. Next there is a soft, marly sand, whitish and usually from 2 to 3 meters thick and without bedding planes. Over all are dunes of medium-grained, reddish-brown, unconsolidated sand. The whole bluff is highly colored and may show shades of brown, red, purple, lemon color and white. These beds nearly all contain more or less iron and lime and in some localities contain a great deal of earthy matter including kaolin and clay.

Further down the coast just south of the village of Touros,

⁶ Roderic Crandall, "Geographia, geologia, supprimento d'agua, transportes e açudagem," Publication of the Ministerio da Viacão e Obras Publicas, p. 31. Rio de Janeiro, 1910.

there is an exposure of yellow, coarse-grained sandstone with beds almost horizontal or dipping gently toward the sea. Fifteen kilometers further south there is a bluff about 3 meters high composed of a sandy clay, white, brown, and reddish colors. It very much resembles the bluff noted near Lagoa dos Mattos.

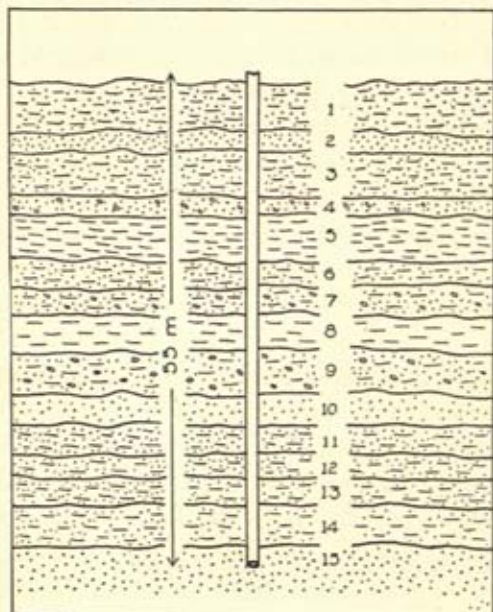


FIG. 3. The log of a typical well drilled in Natal, Rio Grande do Norte.

- | | |
|---------------------------------------|---------------------------------------|
| 1. Fine sand and clay. | 9. Sand and clay with quartz pebbles. |
| 2. Yellow sand. | 10. Yellow sand. |
| 3. Sand and clay. | 11. White sand with clay. |
| 4. Sand and clay with quartz pebbles. | 12. Yellow clay with sand. |
| 5. Clay. | 13. Red sand with clay. |
| 6. Sand and clay. | 14. Coarse sand with clay. |
| 7. Sand and clay with quartz pebbles. | 15. Coarse sand. |
| 8. Clay. | |

These deposits of sediments stretch in an unbroken strip from near Aracaty and probably further north, to Recife and probably further south. Their width varies: At Mossoró it is about 35 kilometers, at Macáu 22 kilometers, at Ceará Mirim 25 kilometers, at Natal about 20 kilometers and at Parahyba about 20 kilo-

meters. Their thickness increases as the coast is approached. At Areia Branca they have a thickness of at least 90 meters, at Macáu of 106 meters, and at Natal of at least 108 meters. I have never found any fossils in them, but Dr. J. C. Branner⁷ describes fossils in yellowish, calcareous sandstone along the coast at Ponta de Pedras, which he refers to the Tertiary. It is very probable, though of course not certain, that these beds are to be correlated with the sands and clays here described in Parahyba and Rio Grande do Norte.

The geologic history of this part of the coast of Brazil, basing our opinion upon the information already given, must have been about as follows: the rocks of the basal complex or the crystalline mass after a long period of erosion were finally submerged along the coast of Parahyba and Rio Grande do Norte during Cretaceous or Pre-Cretaceous times. The sea encroached on the land, much further than the present contact between the crystalline and sedimentary areas. It was during this first period of subsidence that the coarse-grained sandstone was deposited. Following this deposition a moderately pure limestone was laid down directly on top of the sand. Whether or not the land rose and the sandstone was subjected to erosion before the limestone was deposited, is not known definitely. The exposures of bedded sandstone are few, but wherever noted the strata of sand and limestone were conformable. Therefore, I am of the opinion that both were laid down during the same period of deposition, but that the contact marks a great change in physical conditions. Following this period the land rose. Apparently there was little disturbance for the beds are horizontal or they dip gently toward the sea. Considerable erosion must have taken place at this time for the limestone is worn very thin in places. During Post-Cretaceous times the land along the coast was submerged again and the more recent beds of sand and clay were deposited. Physical conditions must have again changed for the absence of calcareous matter in these latter beds show that animal life was scarce. Once more the land rose and has probably remained above the sea from that time until the present day. The surface of

⁷ J. C. Branner, "Geology of the Northeast Coast of Brazil," *Bulletin of Geological Society of America*, Vol. XIII., p. 47. Rochester, 1902.

the sand and clay deposits is more or less calcareous due to the lime-laden waters which pass over it, but the rocks a short depth below the surface are quite free from lime.

With the exception of the region about Mossoró and Assú the entire series of sedimentary rocks seems to be deposited in a fairly even line down the coast, the belt always becoming a little narrower toward the south. In the locality excepted there is a large basin inland. This can readily be explained by the nature of the drainage in that region. The three rivers Jaguaribe, Mossoró and Assú, are the largest along this part of the coast, and although they drain a large area their mouths are close together. Naturally in their immediate vicinity erosion was deeper and more general than in areas of lesser drainage. Hence, when the land sank the water was able to reach much further inland in this vicinity than in any other along the coast of Parahyba and Rio Grande do Norte, and the subsequent deposition covered a correspondingly larger territory.

Other than the sedimentary rocks along the coast there are several areas of stratified rocks, smaller and completely isolated, in the states of Parahyba and Rio Grande do Norte. Chief among these is the sandstone basin of the Rio do Peixe. Beginning at the approximate juncture of the Rio Piranhas with the Rio do Peixe and extending



FIG. 4. Section across the sandstone basin of the Rio do Peixe, Parahyba.

over the divide into the head waters of the Rio Pendencia, a distance of 80 kilometers, there is a basin of reddish sandstone. The basin has a varying width which averages between 9 and 12 kilometers for the entire length, and has, moreover, a long arm which extends more than 12 kilometers up to Belém. It is an isolated area of sandstone in the midst of a vast stretch of crystalline rocks. The typical rock is a reddish and rather fine-grained sandstone, which, in the upper part of the basin, or roughly that part above Souza, is very common

and forms most of the valley floor, as well as the low hills well up toward the contact. As a general thing, however, the margins of the basin, or the part nearest the contact with the crystalline rocks, are composed of a coarser sandstone than the parts further down. In fact, the part nearest the contact is often a conglomerate, having small quartz pebbles, some the size of a hen's egg, imbedded in the sand. As a rule these sandstone beds dip gently to the south or a few degrees to either side of south. There is also evidence of a small syncline near the southern boundary of the valley. This syncline was shown near Acauan and again near São João in relatively the same position. However, it is small and is not likely to prove to be of any economic importance. The reddish and yellowish sandstone is interbedded with a likewise reddish clay. This clay covers so large an area that it must be taken into consideration. In appearance it is very much like the sandstone but of a finer grain. In several places in the valley it was found plainly interbedded with the sandstone. It is most common in the lower part of the basin, that is, it is found from one end to the other but in any one cross-section of the valley the clay would be more likely to be found near the river or in the lower part. The whole of this deposit of sediments is intergraded between a coarse sandstone of a conglomeritic nature, a medium-grained sandstone, a fine-grained sandstone of a partially clayey nature, and a typical clay. At times one may find all these different grades of rocks interbedded in one place.

So far as I know no fossils have ever been found in these rocks. The sandstone very much resembles that which underlies the limestone in the coastal belt, and it is provisionally referred to the Cretaceous. There is a possibility of its being connected with the sandstone of the Serra Araripe. There is also a possibility of its having been connected with the sandstone of the coastal belt. Indeed, it is difficult to account for its presence on any other hypothesis.

The Serras of Martins, Porto Alegre and João do Valle are a series of sandstone capped mountains which rise abruptly to a height of 650 to 700 meters. The last named of these was not visited by the writer. The first two have a layer of hard, quartzitic, coarse-grained sandstone which attains a maximum thickness of about 50 meters, and which lies horizontally on the crystalline rocks. No

fossils have been found, but it is not improbable that this sandstone was also once connected with that nearer the coast. The bases of the Serras Martins and Porto Alegre, are formed of old metamorphic schists. There is a mass of isolated limestone near the base of the Serra Martins. So far as I have been able to ascertain, these sandstone capped serras, the sandstone basin of the Rio do Peixe, and the coastal belt of sediments, form the total of sedimentary areas in the states of Parahyba and Rio Grande do Norte.

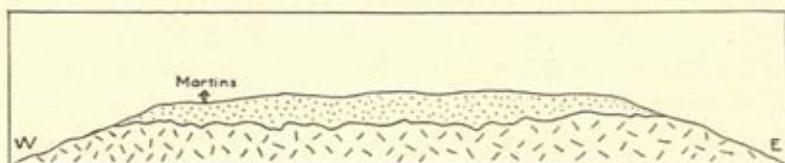


FIG. 5. Section across the Serra Martins, Rio Grande do Norte.

One of the most interesting things in this connection is the relation of the geology to the topography. The crystalline area may usually be recognized by scattered serrotes of hard granite, by occasional mountains which rise abruptly from the surrounding plain, by great, gently undulating stretches, covered with a scattered growth, and by low ridges, steep-sided and rocky. On the other hand the sedimentary area is notable first of all for its vegetation, which assumes the form of an impenetrable forest: often there is a thick undergrowth from 3 to 4 meters in height. The only prominent topographic features are a few low ridges and the broad Chapadas of Apody and São Sebastião, which on the south, end in a low escarpment, but which on the north, slope gently toward the sea. Also, very noticeable are the short streams with their steep banks which cut cleanly through the soft sediments. These hard rocks and undulating plains of the crystalline complex which give rise to a rapid drainage, and the long, almost level stretches on the sedimentary areas, play an important part in the conservation of the water supply.

SUMMARY OF OBSERVATIONS ON THE GEOLOGY OF PARAHYBA AND RIO GRANDE DO NORTE.

I. The two great groups of rocks in the region covered are crystalline and sedimentary.

2. The crystalline division is mainly gneiss and schists and includes the ancient (Archean to Paleozoic) crystalline rocks with bosses and dikes of various eruptives. It covers the greater part of the states of Parahyba and Rio Grande Do Norte.

3. The rocks classified by Mr. Roderic Crandall as the Ceará series are here included with the schists, since they are usually in that form. These particular schists are not all crystalline schists and may include layers or lenses of quartzite and of limestone.

4. The granites form the axes of some of the principal mountains.

5. It is impossible in a short expedition to determine the distribution of the crystalline rocks. They have been metamorphosed and intruded to a remarkable extent, and they seem to have crystallized in a very irregular manner.

6. The typical vegetation on the crystalline area is a scattered growth of low trees and brush of small root development, called caatinga. Caatinga forests, however, are not confined to areas of crystalline rocks.

7. The topography is characterized by great undulating plains, abrupt mountains, rocky, steep-sided hills, and peaked serrates.

8. The crystalline rocks have been subjected to great crushing forces. The schists usually stand at a high angle and the rocks are everywhere cut through by quartz veins which vary in width from a few centimeters to half a meter. Occasionally there are pegmatite veins.

9. The rocks are usually soft and decomposed to a depth of from 3 to 10 meters.

10. The sedimentary series forms the comparatively modern (Mesozoic to Recent) rocks.

11. It is confined for the most part to a comparatively narrow strip along the coast.

12. This series reaches the entire coastal length of the states of Parahyba and Rio Grande do Norte and varies in width from about 120 kilometers in the vicinity of Mossoró, to 30 kilometers at Natal and about 30 kilometers at Parahyba.

13. The sediments thin out on the interior side until their margin

becomes a series of isolated patches overlying the granites and gneiss.

14. The sedimentary rocks have three main divisions:—a deposit of sandstone, one of limestone, and a more recent deposit of sands and clays.

15. The sandstone directly overlies the uneven face of the crystalline rocks. It is of a medium grain, is conglomeritic in places, and is usually of a white or reddish color. It has a thickness of at least 30 meters and probably more. It is exposed in a continuous strip from near Aracaty to Natal and probably further south; its average exposed width is from 8 to 12 kilometers.

16. In general this sandstone dips gently to the northeast. No fossils are known to have been found in it, but on account of its association with the limestone, it is commonly referred to late Cretaceous or early Tertiary age.

17. The sandstone is overlain by a bed of hard, fine-grained, yellowish and grayish limestone.

18. The limestone is exposed in a continuous strip from near Aracaty to Natal and is known to exist in several places between Natal and Parahyba. Its width varies from about 70 kilometers in the vicinity of Mossoró, to 25 kilometers at Assú, and less than 10 kilometers at Natal. It has a thickness of from 30 to 50 meters.

19. In general the limestone dips gently toward the sea—to the northeast. It is of late Cretaceous or early Tertiary age.

20. The contact between the limestone and the underlying sandstone, is marked from União to Assú, by a low escarpment which varies in height from 30 to 100 meters.

21. The limestone in turn is overlain by a partially consolidated deposit of sands and clays. Where these beds are exposed along the coast they are highly colored and contain much iron.

22. The area of sands and clays is exposed in a continuous strip from north of Aracaty, to south of Recife. They have a width which varies from 35 kilometers at Mossoró, to about 15 kilometers at Parahyba. Their thickness at Areia Branca is more than 90 meters, at Macáu it is 106 meters, and at Natal it is more than 108 meters.

23. At only one or two places along the shore are these sedi-

ments consolidated, and the structure when it is reliable shows horizontal bedding. I have not found any fossils in these beds but Dr. J. C. Branner reports fossils from similar beds at Ponta de Pedras which he refers to Tertiary age. It is not unlikely that these beds (in Parahyba and Rio Grande do Norte), are of the same age.

24. The Serras of Porto Alegre and Martins are capped with layers of quartzite, about 50 meters thick. Mr. Roderic Crandall reports that the Serra João do Valle is a similar mountain.

25. No fossils have been found in the sandstone of the above named serras.

26. The valley floor of the basin of the Rio do Peixe is composed of a reddish sandstone, conglomeritic in places and interbedded with a reddish clay. This area is from 9 to 12 kilometers wide and is about 80 kilometers long. It is entirely surrounded by crystalline rocks.

27. The age of this sandstone of the Rio do Peixe is provisionally referred to the Cretaceous, but so far as is now known no fossils have been found in it.

28. It will be noticed that practically the entire sedimentary belt along the coast is tilted gently toward the sea.

29. There is a series of shifting sand dunes along the coast especially noticeable in the vicinity of Natal.

30. There are many clay beds in the sediments along the coast. Some of them may be of economic value.

DESCRIPTION OF PLATES I-IV.

PLATE I.

Geologic map of the states of Parahyba and Rio Grande do Norte, Brazil.

PLATE II.

A. Part of the Chapada do São Sebastião, showing the topography and the dense caatinga growth.

B. Exposure of limestone near Passagem Funda, Rio Grande do Norte.

PLATE III.

A. Isolated serrote of granite in the midst of an area of schist and gneiss, near Martins, Rio Grande do Norte.

B. Exposure of sandstone along the Chapada do Apody, near Passagem Funda, Rio Grande do Norte.

PLATE IV.

A. Serra do Porto Alegre, Rio Grande do Norte. The flat summit is of sandstone which rests on crystalline rocks below.

B. Part of the limestone scarp of the Chapada do Apody showing a luxuriant growth of vegetation.





38° 37° 36° 35° **GEOLOGIC MAP** OF THE **STATES OF PARAHYBA** AND **RIO GRANDE DO NORTE** **BRAZIL**

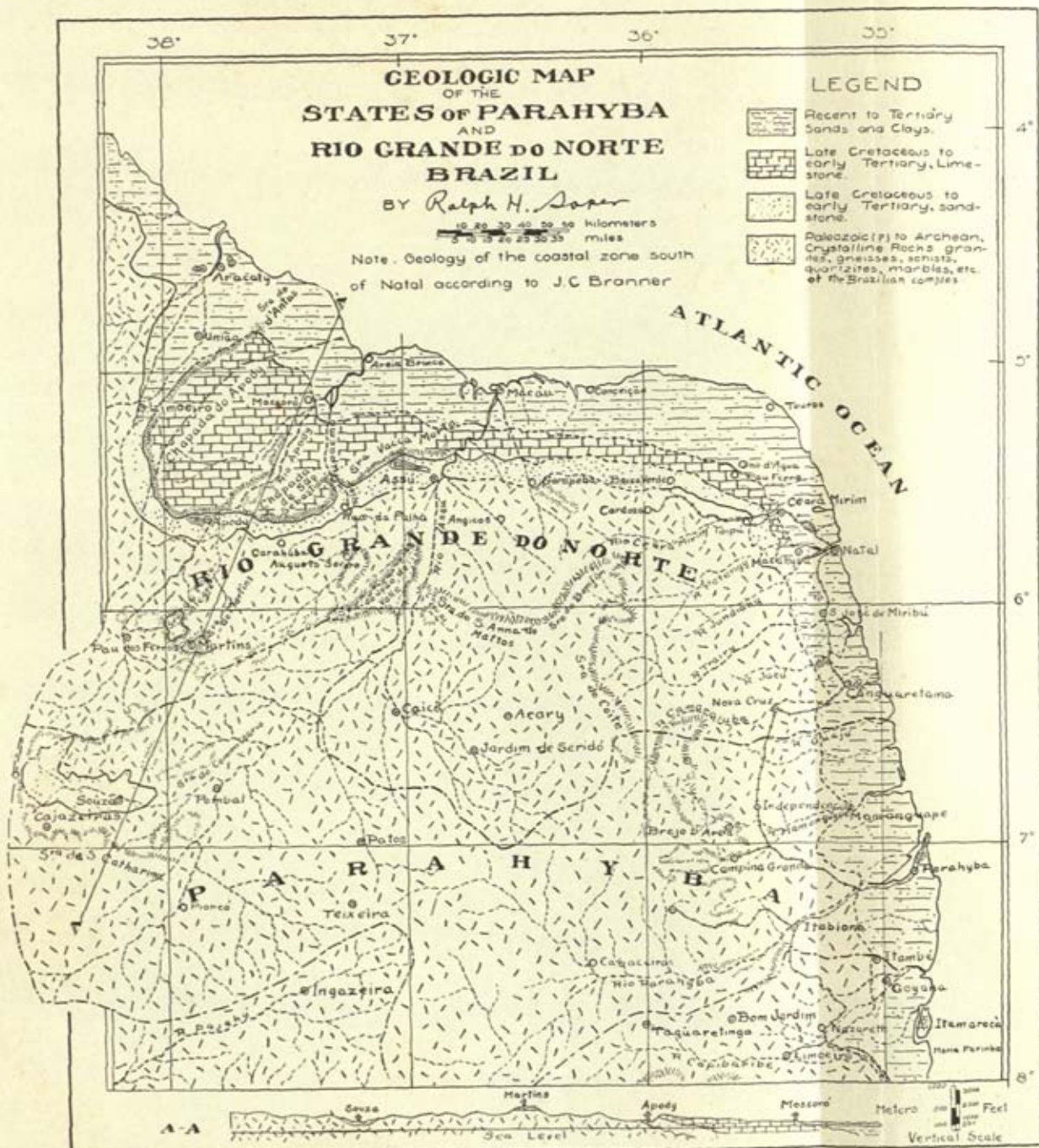
BY *Ralph H. Saper*

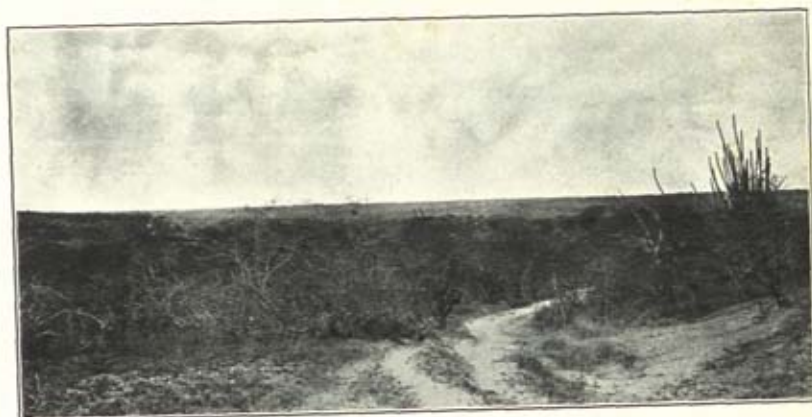
0 10 20 30 40 50 kilometers
0 5 10 15 20 25 30 35 miles

Note: Geology of the coastal zone south
of Natal according to J.C. Branner

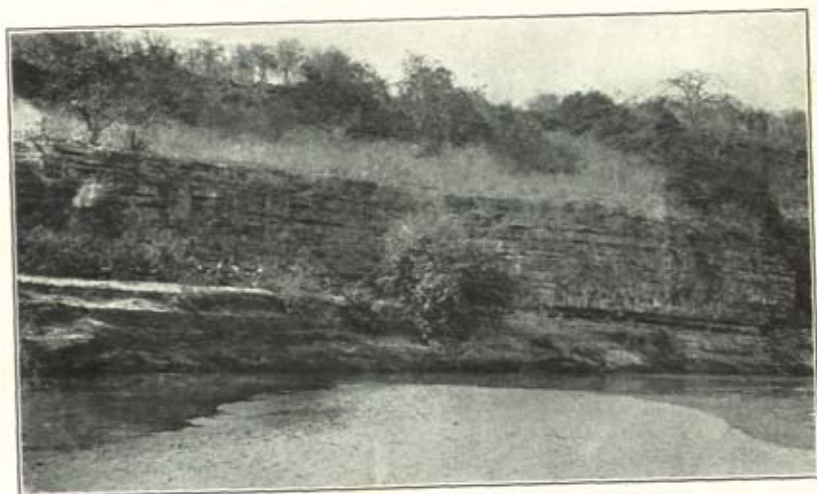
LEGEND

-  Recent to Tertiary Sands and Clays.
-  Late Cretaceous to early Tertiary Limestone.
-  Late Cretaceous to early Tertiary sandstone.
-  Paleozoic(?) to Archean Crystalline Rocks, gneisses, schists, quartzites, marbles, etc. of the Brazilian complex.

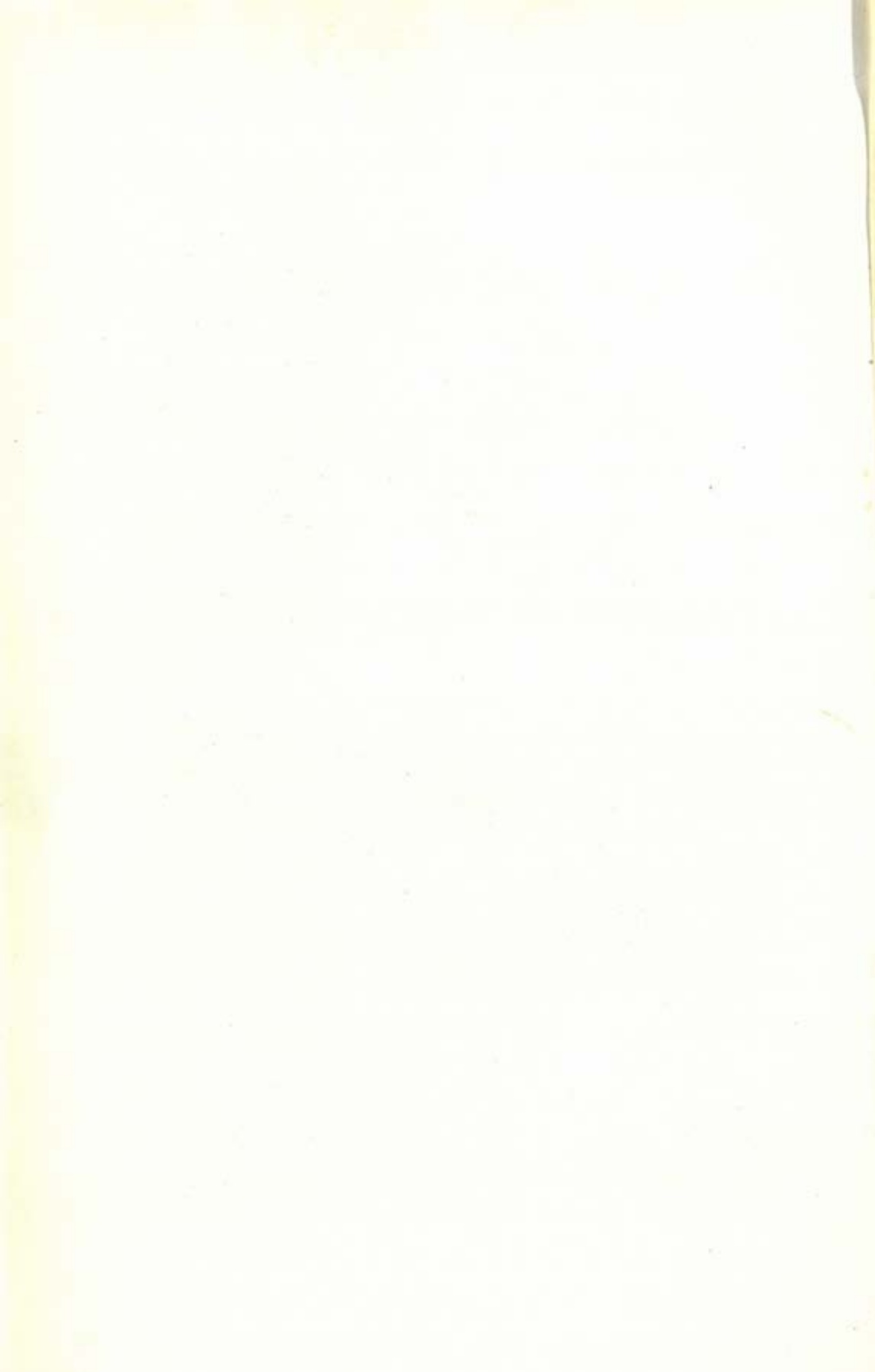


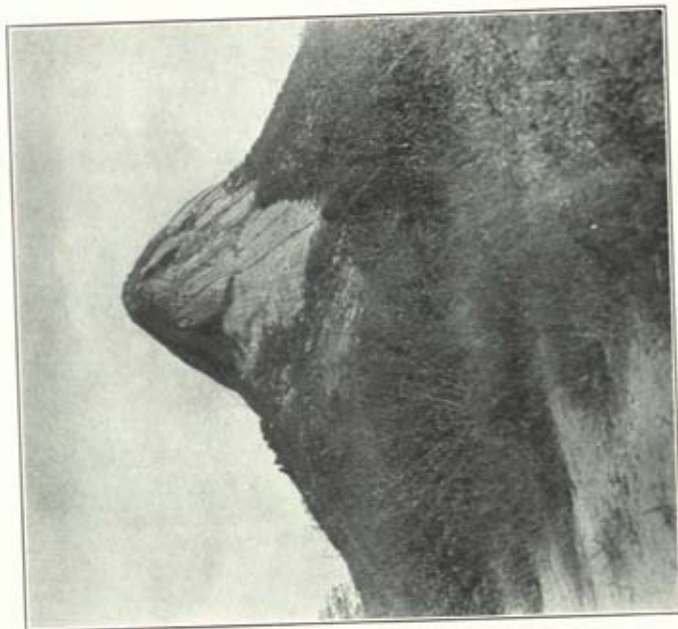


A. PART OF THE CHAPADA DE SÃO SEBASTIÃO, SHOWING THE TOPOGRAPHY AND THE DENSE CAATINGA GROWTH.

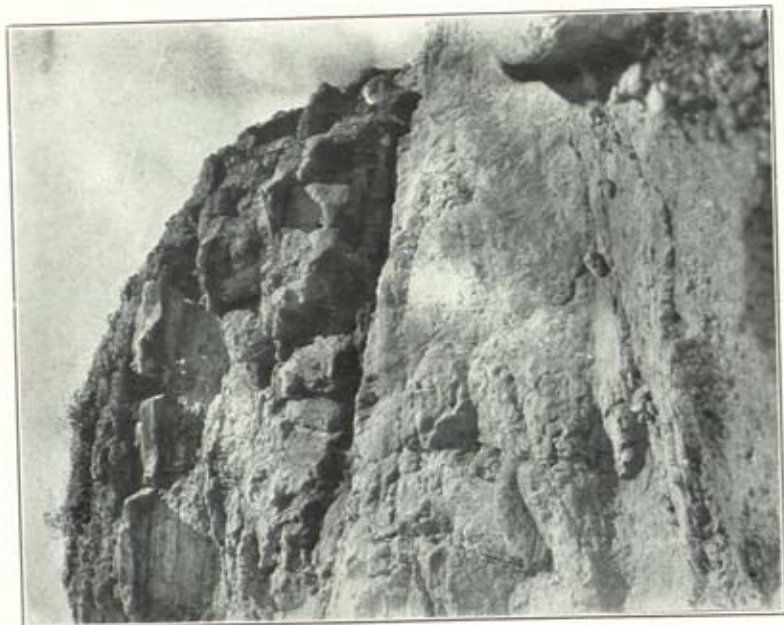


B. EXPOSURE OF LIMESTONE NEAR PASSAGEM FUNDA, RIO GRANDE DO NORTE.

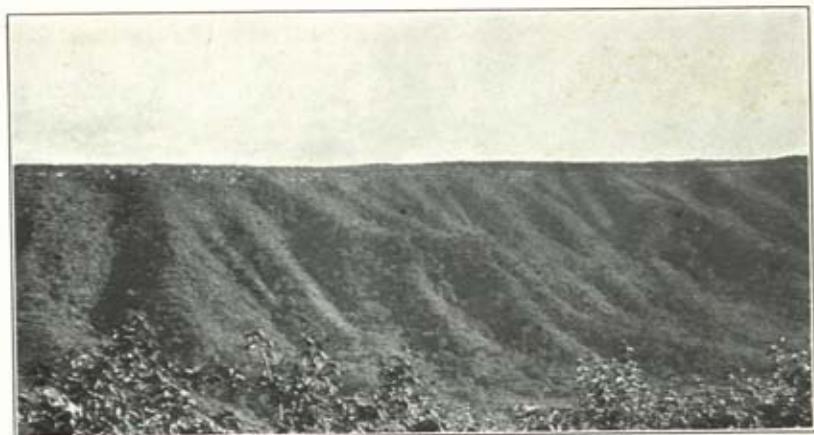




A. ISOLATED SERROTES OF GRANITE IN THE MIDST OF AN
AREA OF SCHIST AND GNEISS, NEAR MARTINS, RIO
GRANDE DO NORTE.



B. EXPOSURE OF SANDSTONE ALONG THE CHAPADA DO APODY,
NEAR PASSAGEM FUNDA, RIO GRANDE DO NORTE.



A. SERRA DO PORTO ALEGRE, RIO GRANDE DO NORTE. THE FLAT SUMMIT IS OF SANDSTONE WHICH RESTS ON CRYSTALLINE ROCKS BELOW.



B. PART OF THE LIMESTONE SCARP OF THE CHAPADA DO APODY SHOWING A LUX-
URIANT GROWTH OF VEGETATION.

INTERRELATIONS OF THE FOSSIL FUELS.

I.

BY JOHN J. STEVENSON.

(Read April 14, 1916.)

PEAT AND THE TERTIARY COALS.

Prefatory Note.—In an earlier treatise,¹ the writer considered some problems bearing upon the accumulation of coal in beds. Other, but closely related, problems will be considered here in the effort to ascertain how closely the fossil fuels, aside from petroleum, are related to each other in their physical and chemical characteristics as well as in their mode of accumulation. In preparing for these studies, the writer has travelled scores of thousands of miles in foreign regions to secure information respecting disputed localities and, in this land, he has made examinations in almost all of the coal-producing states. But life is short and distances are great; a man can gather little by direct study; to secure the knowledge necessary for intelligent discussion of the subject, he must collect and compare, as far as possible, the observations reported by others. This has been attempted; several thousands of reports, notes, memoirs and monographs have been read and the abstracts have been digested, in so far as they contained matter bearing on the problems in hand. All citations, except where otherwise stated, are at first hand.

Some may regard study after this fashion as wasted force, especially because the matters involved appear to possess little of economic interest; but the labor has been performed without compulsion and with no hope of reward, except that of criticism by

¹ "The Formation of Coal Beds," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 1-116, 519-643; Vol. LI., pp. 423-553; Vol. LII., pp. 31-162.

those who may regard the work as defective and the conclusions as unsound. The study has been made solely to find solutions of problems which had perplexed the writer during more than 45 years. The results are presented, not because they are final, but in the belief that those students who take up the investigation anew at some future time, when knowledge shall have been increased, will find their labor lessened by this opening of by-paths in the literature; and equally in the hope that credit may be restored to some of the earlier students, whose work has been forgotten or ignored.

The autochthonous origin of coal is taken for granted in this work; argument in favor of that doctrine has been presented in the writer's "Formation of Coal Beds."

The various terms applied to fossil fuels have, in a general way, sufficiently definite significance. When one hears the words peat, brown coal, coal, anthracite, he recognizes each as referring to a substance with which he is familiar. Museums contain specimens from many localities, properly labeled, so that the names become for students thoroughly definitive. Tables of comparative analyses are given in textbooks, which mark off the limits of the several substances with ample distinctness. It is true that in most textbooks and in most lecture courses there is proper though somewhat incidental statement that the specimens represent, for the most part, what may be termed typical forms, and that from each type in each direction to the next the transition is practically imperceptible. Yet that that conception lacks concreteness, the more so because each appears to be characteristic of a certain stage in the earth's history. But the names are those of groups, each comprised of members differing greatly in chemical and physical features; and there are strange overlappings, for in the groups less advanced chemically, one finds substances very similar to some in the more advanced, while in the latter he occasionally meets with forms almost indistinguishable from some of the former.

Since the extent of chemical change, as a rule, increases with the age of the deposit, it is most convenient to consider the fuels in the order of their occurrence in time.

PEAT.

Peat is the familiar accumulation of more or less changed vegetable matter observed in localities sufficiently moist. It is most abundant in Pleistocene and Recent deposits, but a very similar material occurs in the Tertiary and, even in the Carboniferous, one finds a substance, which in hand specimens can hardly be distinguished from well-dried peat.

Conditions Requisite for Accumulation.—As asserted long ago by Alex. Brongniart, constant supply of moisture in considerable quantity is a prerequisite for growth of peat. Ponds and shallow lakes in glacial drift have been favorite localities in the northern part of the temperate zone, where deposits vary in extent from a few square rods to several scores of square miles. Areas of deep water are made shallow by accumulating animal and vegetable remains, largely of humble types, and eventually become filled with normal peat. But such deposits are, individually, of small extent, though they are so numerous that, collectively, they cover much of the formerly glaciated surface within North America and Europe. Peat areas of greatest extent are those originating on coastal plains or on those bordering rivers, where the sluggish drainage is checked readily by petty obstacles and small patches of swamp become united until a great space has been occupied. Some deposits of this type have an area of many hundreds of square miles.

Peat has provided fuel for much of northern Europe during centuries and the literature with reference to it is voluminous; but it has no economic importance within the tropics, so that definite statements respecting its occurrence are comparatively few. Explorers naturally were concerned more with geography and anthropology, so that one finds usually little aside from incidental statements to the effect that a region is swampy, boggy and difficult to traverse. But more than one hundred years ago, Jameson² stated that Anderson had received peat from Sumatra. Certainly the conception that true peat is confined to the temperate zones is erroneous. Livingstone in 1858 and 1866 presented abundant evi-

² R. Jameson, "An Outline of the Mineralogy of the Shetland Islands, and of the Island of Arran," Edinburgh, 1798, pp. 151-153.

dence of its existence in equatorial Africa. Wall and Sawkins in 1860 found peaty deposits on the island of Trinidad, which even after desiccation at 300° F. contained 35 per cent. of organic matter. In 1870, Hartt reported his discovery of peat in the state of São Salvador, S.L. 10°, as well as in the state of São Paulo, both in Brazil. Brown described peaty deposits in the Demarara region; "from Santa Rosa on through the Staboos, the head of the Barabara River, there are many tracts of open land, composed of black bog-mud formed by decayed vegetables and covered with a growth of rank sedges and rushes." Some portions of these "savannas" are permanent swamps, in which the Ita palm, *Mauritia flexuosa*, is one of the prominent trees, rising to the height of 60 feet. Harrison, in discussing the same region, says that peat occurs in many of the low-lying coast lands, where it is from 1 to 10 feet thick, though usually not exceeding 4 feet. Considerable portions of this "pegass" land are covered with the Aeta palm.³

Long ago, Lyell described the general features of the Dismal Swamp and of the cypress swamps of the lower Mississippi River, both of which were discussed in detail by Shaler at a later date. Kuntze⁴ in 1895 described the vast wooded swamp, a mass of peat extending for 3 degrees of latitude along the Lourenço River of Brazil. The conditions in Florida, where the peat areas are great and the deposits often very thick, have been described in detail by Harper, and several observers have made note of the peat in Bermuda. Livingstone, Cameron, Lugard and Miss Kingsley have presented proof that peat is abundant in equatorial Africa.⁵

During the progress of the Dutch explorations in Sumatra, 1891, Koorders observed a great Flachmoor covered with a 30-meters-high mixed forest growing on peat, which Larive's measurements

³ G. P. Wall and J. G. Sawkins, "Geology of Trinidad," London, 1860, pp. 62, 63; C. F. Hartt, "Geology and Physical Geography of Brazil," Boston, 1870, pp. 365, 509; C. B. Brown, "Physical, Descriptive and Economic Geology of British Guiana," Geol. Survey, London, 1875, pp. 34, 91; J. F. Harrison, "Pegass of British Guiana," *Quart. Journ. Geol. Soc.*, Vol. LXIII, 1907, p. 292.

⁴ O. Kuntze, "Geogenetische Beiträge," Leipzig, 1895, pp. 67, 68.

⁵ For detailed statement of these observations in tropical and subtropical regions, see "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.*, Vol. L, 1911, pp. 565-573.

proved to be 9 feet thick. Examination, microscopical and chemical, showed that this peat has structure and composition wholly similar to the peat of Europe, though the plants from which it is derived are different.⁶

Molengraaff⁷ studied central Borneo in 1893-94. On many pages he notes the presence of marshes along the larger rivers and describes them as boggy. These marshes in many cases are densely wooded though frequently covered with water during several months in succession. A considerable deposit of peat was seen near the Tebaoeng River. In ascending Babas Hantoe, one of the Madi mountains, he reached, at 500 meters above the sea, an extensive plateau, on which the forest contains many conifers, these increasing upward until at 700 meters they were paramount. There a soft soil had been reached, mosses had appeared and the character throughout was that of a forested swamp. The deeply trodden narrow path wound among wet spongy cushions covered with moss until at 1,000 meters the area was a genuine morass and advance could be made only by leaping from the root of one tree to that of another. The altitude is not sufficient to remove the locality from tropical conditions, as this is almost directly under the equator. On the other side of the mountain, he descended into a valley, which at first showed patches of marshy forest with peat. Farther down, the peat patches became continuous and he soon recognized that the whole of this valley and probably the whole Madi plateau are covered with a marshy forest, standing in a thick layer of peat, which consists of the half decayed remains of all kinds of trees, shrubs and mosses, a true tropical peat bog; but, like tropical fens generally, it is composed chiefly of remains of trees, thus contrasting with fens of temperate zones, which originate so frequently from mosses and a limited variety of shrubs. The yellow-brown fen water from this peat area flows into the Tebaoeng River.

Koorders, as cited by Potonié, reported that, in old Javan and

⁶ H. Potonié, "Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt," 5te Aufl., 1910, pp. 152-160.

⁷ G. A. F. Molengraaff, "Geological Explorations in Central Borneo, 1893-94," Leiden, 1902, pp. 83, 84, 307, 310. The citations are from the edition in English; the edition in Dutch was published in 1899.

Sumatran forests, where hard woods grow, fallen trees are numerous, which though decades old are still in condition good enough for export. Molengraaff gives an illustration more remarkable, because the conditions are not constant. The Lake district of the Upper Kappewas River is merely the overflow area during flood time. The lakes contract during the dry season, leaving only shallow channels in which fish accumulate. The Malays gather in camps to harvest the fish and the camp fires frequently spread, causing great destruction in the forest. In one portion of this district, a great "submerged" forest remains, composed of medium-sized charred stumps, in varying stages of decay and all broken off at approximately the same height. A sprinkling of younger trees was seen, but owing to the unfavorable conditions—flooding and fires—the forest cannot recover. This locality was described by Ida Pfeiffer in 1846, when the features differed little from those observed by Molengraaff, almost half a century later. Evidently, decay of rooted stumps may be as slow under the equator as in temperate regions.

Wichmann⁸ gathered available information respecting peat deposits in the Indian archipelago, summarizing observations by Jung-huhn, Koorders, Molengraaff, Machielson, Schwaner, Teyssmann, Van Nouhys and himself. The largest fen in Java is in Samarang; about 2,500 hectares have been brought under cultivation but not less than 1,500 still remain as swamp. Borings at one locality show that the peat is from 30 to 31 meters thick and "peat islands" have risen in it at various times. The Javan peat is an inferior fuel as it contains much ash; that from Kapogan has 27 per cent.

Very many swamps within the east coast residency of Sumatra have been drained and placed under cultivation; but much still remains untouched. A great fenland of 80,000 hectares, between the Siak and Kampar rivers, has been known long time and it has been described by Koorders, botanist to the Ijzerman expedition of 1891. As Wichmann presents the matter, peat is evidently a commonplace in Sumatra. He refers to Molengraaff's observations in central Borneo. W. J. M. Machielson found fens along several rivers in another portion and C. A. L. M. Schwaner reported them from

⁸ C. E. A. Wichmann, "The Fens of the Indian Archipelago," *K. Akad. Wetensch.*, Amsterdam, Vol. XII., 1909, pp. 70-74.

several localities in the south and east divisions, where all the streams are blackwater. Some of the Borneo peat is very good, that collected by J. W. Van Nouhys containing only 4.58 per cent. of ash.

A very great part of the fenland in the Archipelago has been drained and converted into rice, sugar cane or tobacco plantations, but Wichmann estimates that the area of existing fens exceeds 1,000,000 hectares or more than 3,800 square miles. The uniformity of climatal conditions prevents the variations observed in fens of colder regions. The structure, in Wichmann's opinion, resembles that seen in the Coal Measures, where roots of *Lepidodendron* and *Sigillaria* are found in the floor of coal beds; so in the tropical fens, the trees are rooted in the subjacent clay. As accumulation of peat does not choke the trees rapidly, these frequently remain erect in the peat.

It would seem to be sufficiently evident that a hot climate offers no hindrance to the accumulation of peat, if only the conditions exist which are required for that accumulation in a cool climate.

Even a very severe climate does not prevent the growth of peat. Nathorst⁹ visited the Renntier-tal of Spitzbergen in 1882 and saw there, resting on the river débris, 0.25 meter of clayey peat underlying 2 meters of peat: he cites Gunnar Andersson as stating that the upper division consists chiefly of brown moss, but that some layers are crowded with leaves of *Salix polaris*. Nathorst found a leaf of *Salix reticulata* in the underlying impure peat. Andersson believes that peat-formation has ceased in Spitzbergen and that the deposits are relics of a less cold period. Be that as it may, there can be no doubt that bogs are numerous, though in many instances they are thin. The writer in 1904 found enough peat on both sides of Advent bay, N.L. 78°, to make walking not too attractive and there was living vegetation on the surface in many places. A. E. Stevenson reported that the black mud is more than knee-deep for considerable distances along the shore of Icefiord to more than 12 miles south from below Advent bay. Peat was seen on Bell sound.

⁹ A. G. Nathorst, "Beiträge zur Geologie der Bären Insel, Spitzbergen, und des König-Karl. Landes," *Bull. Geol. Inst. Univ. Upsala*, Vol. X., 1910, p. 403.

Russell¹⁰ has described conditions on the tundra and in the interior of Alaska. He says that "without exaggeration, it may be stated that the whole of Alaska, excepting the steepest rock slopes and the tops of high mountains, is covered with a dense carpet of moss." The reported thickness of peat on the tundra is from 2 to 150 even to 300 feet. The peat is growing, though the depth to frozen material is only from 8 to 14 inches. Capps¹¹ has described an Alaskan peat deposit, exposed in a bluff for more than a mile. The peat, 39 feet thick and resting on unconsolidated glacial till, is fibrous, with abundant stumps and roots, but probably consists mostly of *Sphagnum*. The mass is divided at 7 feet from the top by 2 feet of white volcanic ash. The surface beyond the edge of the bluff is covered with a thick coat of *Sphagnum* and supports a dense forest of spruce with little undergrowth. The peat, ash and till are permanently frozen at a few inches back from the edge of the bluff, though that is subjected to the long hours of summer sunshine. Even the surface is frozen at a depth of 6 inches in early July.

The arrangement of roots shown by spruce trees growing at the edge of the bluff as well as by the stumps, which compose a great part of the deposit, is wholly unlike that ordinarily observed. Spruce growing on solid ground, frozen or not, has radial roots, parallel with the surface and penetrating only a few inches; but, at this White River locality, the roots of trees growing on the edge of the bluff and those of stumps buried at different levels in the peaty mass have a very different arrangement. Instead of a single, flat-based set of radial roots, these trees all show a central stem, often several feet long, from which roots branch off at irregular intervals, with an upper set of roots near the surface, corresponding to those of the normal tree. Investigation proved that roots below the frost-line are still undecayed, though they differ in color from the uppermost set of radial roots and evidently are no longer active. Capps reached the conclusion that, in each case, the seedling spruce, having established itself on the mossy soil, sent out the normal radial roots; but

¹⁰ I. C. Russell, "Notes on the Surface Geology of Alaska," *Bull. Geol. Soc. Amer.*, Vol. I., 1890, pp. 125, 126, 129.

¹¹ S. R. Capps, "An Estimate of the Age of the last great Glaciation in Alaska," *Journ. Washington Acad.*, Vol. V., 1915, pp. 108-115.

the rapidly thickening moss and consequent rising plane of frozen ground cut off nutriment from the existing roots, necessitating the formation of a newer set nearer the surface. He measured one tree, which had 24 inches of vegetable matter above the lowest horizontal roots. At 6 feet above the surface it had 373 annual rings, so that the growth of the peaty mass had been at the rate of one foot in about 200 years. One foot of the compact peat lower down represents a much longer period.

Tyrrell¹² has studied peat deposits in a great part of Canada. He notes that in northern Canada the peat, 10 to 12 feet thick, often rests on a plate of clear ice. The water for this came from springs below the permanently frozen ground and it favored the growth of peat mosses in summer. The peat of Canada, except in the southern portion, consists practically of undecomposed moss from top to bottom, as the intense cold prevents change, the lower portions being frozen. In the Klondike region, the moss layer is rarely more than 5 or 6 feet thick, but there may be below it a variable mass of "muck," a mixture of sand and vegetable matter, the latter not from mosses. This muck he thinks originated in part as vegetable mould which has slidden down into the narrow valleys. It may contain about 30 per cent. of plant material.

Cochrane,¹³ who crossed Siberia long ago, was more interested in the people, the roads and the weather than in geology, but he has given some notes respecting localities in eastern Siberia, where his progress was impeded. On the return journey from Nishney Kolymsk, N.L. 69°, E.L. 160°, southwestwardly to Okotsk, N.L. 60°, E.L. 142°, he travelled over a region of mostly overflowed meadows, alder country and "marshy swamps"; the last part of the distance, 7 days' journey, is a continuous swamp covered, at times, with fallen trees. Between Okotsk and Yakutsk, N.L. 62°, the route from the Okota River passes for long distances across wooded swamps; for 50 miles east from the Aldan River, the region is a

¹² J. B. Tyrrell, "Crystophenes or Buried Sheets of Ice in the Tundra of Northern America," *Journ. of Geology*, Vol. 12, 1904, pp. 232-236; also letter of August 3, 1915.

¹³ J. D. Cochrane, "Narrative of a Pedestrian Journey through Russia and Siberian Tartary," Amer. ed., Phila., 1824, pp. 220, 225, 234, 238, 319, 325, 342.

most dreary, swampy plain, the road being a wooden causeway in the latter half of the distance. Forty miles of swamp were encountered in the 80 miles east from the Lena River. Cochrane thinks that Siberia is an impregnable province, as, owing to the vast extent of the swamps, a few hours of work would render any one of the roads impassable.

Atkinson¹⁴ has given some information respecting western Siberia between Ekatherineburg and Tomsk. In going from Omsk to Kainsk, a distance of about 200 miles, he crossed much swampy area, continuous at one time for 31 miles. There are many lakes south from Kainsk in an area of 150 by 40 miles, all of them surrounded by broad belts of reeds. Morass prevails between the lakes as well as for nearly 100 miles farther southward.

Nordenskiöld's¹⁵ references to peat are merely incidental. His studies were along the coast and excursions into the interior were, for the greater part, comparatively short. The plain on the Yalmal peninsula, west from the mouth of the Yenisei, is tundra-like, full of marshes and streams; on Taimur land farther west, the plains are covered with a continuous, very green vegetation, a mixture of grasses and allied plants with mosses and lichens. In the Gyda peninsula, where Schmidt obtained remains of Mammoth in 1866, N.L. 70°, the stratum containing the remains rests on marine clay and is covered with sands alternating with beds of decayed plant material, completely corresponding with peat deposits formed in lakes of the tundra. The description of the Chukch peninsula, in northeast Siberia, is very similar to that given by Cochrane.

Incidental references in a description by the Comité géologique of Russia¹⁶ give some conception of the marsh-covered area on both sides of the Transsiberian railway. The Steppe de Baraba, between the Irtych and the Ob, about 10 degrees of longitude, is described as differing from steppes at the west in that it has many great marshes

¹⁴ T. W. Atkinson, "Oriental and Western Siberia," New York, 1858, pp. 151, 153, 156.

¹⁵ A. E. Nordenskiöld, "The Voyage of the Vega," New York, 1882, pp. 154, 253, 309, 422.

¹⁶ "Aperçu des explorations géologiques et minières le long du Transsibérien," Publié par le Comité Géologique de Russie, 1900, pp. 4, 52, 63, 113.

and forests of birch and aspen. Beyond the Ob, the road passes for about 50 miles through a marshy forest of pines and firs, which extends from near Tomsk southward for more than 300 miles almost to the head of the Kia River. In the area west from Lake Baikal, within the drainage area of the Yenisei, there are impassable marshes of vast extent, sometimes forested—the Taiga. This condition exists between the Kau and Oka Rivers and northward to the Angara. Beyond Lake Baikal, broad valleys hold great marshes covered with vegetation throughout and conifers are abundant in such localities. East from the Yablonovy mountains, the Taiga is characteristic of moist area; pines, firs and black birches are the common forms.

True peat is present in localities where the required conditions appear to be wanting. The so-called forest peat has accumulated to a thickness of several feet in many places within the Rocky Mountain region, the material being merely offal from dense forests of giant firs. In northern New England, one often sees the surface in railroad cuts more or less covered with moss-peat, though the rock is a gravelly sand. This is wholly similar to the Rohhumus, seen so commonly on rock surfaces within forests of both Europe and North America. But the needed conditions are here, though not sufficient to encourage rapid growth. The offal from the trees is abundant and retentive of water, while the moss, once saturated, parts very slowly with its moisture.

Extent of Peat Deposits.—As already stated, a peat deposit may cover only a few square feet or it may cover an area of hundreds even thousands of square miles. The subtropical Everglades of Florida embrace not far from 7,000 square miles; the partly living, partly buried peat of Holland, Belgium and north France has nearly as great extent, as shown by Lorie. Russell's exploration of Alaska led him to assert that peat covers not only the vast tundra but also most of the wooded region as well as of the river plains. The buried deposit of the Ganges delta has been found in numerous borings within a space of more than 2,500 square miles. Skertchly has shown that in the Fenland of England the peat is practically continuous throughout 1,800 square miles.¹⁷ Great areas exist on the north

¹⁷ R. M. Harper, "Preliminary Report on Peat Deposits of Florida," 1910; J. Lorie, "Les dunes intérieures, les tourbières basses et les oscillations du

German border some of which are comparable to the English Fenland. In the majority of the cases cited, accumulation occurred on coastal plains, but the great rivers of Alaska, Sumatra, Paraguay, Brazil and other lands flow amid vast plains, which are peat covered in much of their extent.

The total area, within which peat has been accumulating since the Quaternary began, probably exceeds that in which similar deposits accumulated during any prior period of similar duration. That is not to say that contemporaneous deposits were at any time continuous throughout the area; they were not and they are not, any more than brown coal or stone coal was continuous throughout the regions in which rocks of the respective ages are found. One must always bear in mind that the great deposits of peat did not begin at the same time throughout their present extent. It is altogether probable for all, as it is certain for many, that originally they were small separated patches, beginning in favorable localities and becoming united by transgression. This process is not confined to low-lying areas; Loricé¹⁸ has proved its importance in the Hochmoors of Holland. If conditions favoring growth were checked, the individual deposits would remain isolated.

Growing peat offers great resistance to erosion, as is well-known to those who are familiar with conditions on streams which are subject to violent floods. But where the accumulation is on a permeable yielding material, it may be floated off after long continued flooding. A good illustration has been given by Carpenter,¹⁹ who, in describing a ride through the Panama canal, says that on Gatun lake he found floating islands, tropical swamps lifted from their foundations by the rising water, some of them several acres in extent. Other notes by this author may be given here, though

sol," *Arch. Mus. Teyler*, II., Vol. III., 1890, pp. 424-437; I. C. Russell, "Surface Geology of Alaska," *Bull. Geol. Soc. Amer.*, Vol. I., 1890, p. 129; C. Lyell, "Antiquity of Man," 1871, pp. 336, 337; W. T. Blanford, "A Manual of the Geology of India," 1879, p. 400; S. B. J. Skerthly, "The Geology of the Fenland," *Mem. Geol. Surv. of Great Britain*, 1877.

¹⁸ J. Loricé, "Les hautes tourbières au nord du Rhin," *Arch. Mus. Teyler*, II., Vol. IV., 1893, p. 169.

¹⁹ F. G. Carpenter, "Steaming through the Canal," *Los Angeles Times*, January 10, 1914.

they concern matters to be considered on another page. He was surprised by the abundance of floating and aquatic plants. Already, within the few weeks of the lake's existence, great beds of water lettuce and of water hyacinth had covered much of the surface and were associated with extensive patches of green scum. The water hyacinth had become a pest. The destruction of forests had been rapid; non-water-loving trees were killed by gradual rise of the water-level, but palms showed great power of endurance. Frequently one of the latter is seen with its trunk completely submerged and only the crown of leaves showing above, resembling a bunch of gigantic ferns on the surface.

But when dried by exposure to light and air peat is unstable material. Change in direction of drainage may deprive a considerable area of the needed moisture and growth will be stopped. Unless the surface be invaded by trees, running water will break continuity of the bog and that will be ruptured into "hags," of which Scottish writers have given vivid descriptions. In a moist climate, this process of destruction is slow, as is seen in much of England and Scotland, because peat absorbs moisture and retains it with great tenacity. It may well be that growth may be checked or wholly stopped in one portion of an area while it continues in another, as in the Fenland of England, where peat still grows in one district, though the general climatic change has caused cessation elsewhere. If untoward conditions continue, the peaty cover becomes desiccated and is removed by the wind or other agencies—a fact which is unpleasantly familiar to those who have cultivated drained peat bogs.

Peat-forming Plants.—Peat, being merely vegetable material undergoing chemical change with greater or less exclusion of oxygen, may be the product of any group of plants. The popular belief, based on surface study of bogs in northern Europe, has always been that mosses are the chief source of material for peat; and this no doubt led to the conception that no true peat is to be found within the tropics, since neither *Sphagnum* nor *Hypnum* prospers amid tropical conditions. Yet more than 100 years ago

Alex. Brongniart²⁰ announced that peats, consisting wholly of leaves, had been observed in Holland and that similar deposits, formed of leaves from resinous trees, occur in the Jura. There are very many peat deposits without *Sphagnum*. It and other mosses occur rarely in the peats of Florida and it seems to be wanting in the Kampar-Siak area of Java. Molengraaff asserts that mosses contribute little to the peats of central Borneo. C. A. Davis has shown that *Sphagnum* is a comparatively late comer into the Michigan peats and that it is still absent at a great proportion of the localities. Even in northern Europe, many observers have made it clear that mosses are only a few of the peat-forming plants; and in the older deposits there are thick benches in which *Sphagnum* is almost or altogether wanting. But mosses are all-important in arctic and sub-arctic deposits of this day, while they are comparatively unimportant in those of the temperate and sub-tropical as well as tropical areas.

Sedges appear to have been the most important peat producers in much of the north temperate zone; but a peat deposit is not the product of any single plant or group of plants, though this is not to deny the existence of such deposits, for they do occur under exceptional conditions. In the southern part of the United States, one finds conifers and deciduous trees making the chief contributions; the condition is evidently the same in central Borneo, where according to Molengraaff, the peat consists almost wholly of remains of trees, and Koorders makes a similar remark respecting Java. Any plant, apparently, may become a peat-maker; the hyacinth, introduced into Florida, where it threatened to ruin the navigable rivers, has become a peat-producer of no little importance. Certain members of the palm family contribute to the peat deposits of Florida and it appears altogether probable that, when the peats of the Amazon, Orinoco and Paraguay have been studied, palms will be found among the most important of the contributing plants.

It is well known that the sedge-association, in advancing from the shore of a lake or pond, is very apt to form a floating mat. One

²⁰ Alex. Brongniart, "Traité élémentaire de minéralogie," Paris, 1807, T. II., p. 41.

finds this shown in the Sudd of the Upper Nile. Willey²¹ speaks of that as the serious obstacle to navigation between Khartoum and Gondokoo. The principal interruption is 25 miles long and within 150 miles there are three others aggregating 60 miles. The growth is very rapid after an unusually high flood in the upper rivers, which brings down much vegetation and sediment; but if the rainy season be short, the growth is checked and the current carries out the young plants, not yet strong enough to resist. The top in the older denser areas is so dry that it can be burned, but the mass is so matted that it must be cut with saws and the pieces dragged away. This Sudd consists mostly of water-papyrus and a bamboo, known as elephant grass, with a convolvulus creeping over all. Besides this *in situ* material is more or less of transported stuff. One would imagine that this last would be in comparatively small proportion on the lower sections as most of it would be stopped by the first raft.

Wright²² cites Willcox to the effect that the Sudd interferes seriously with the river's flow. It causes division into numerous streams, which lose themselves, north from Lado, N.L. 6°, in the extensive swamps; Willcox suggested that the channel could be opened by dredging and could be kept open by planting willows on the banks, which would enable the strong current to prevent closing. The absence of willows along the banks makes control of the swamps impossible. Wright cites also Lord Cromer, who notes Major Peake's discovery that the Sudd is not simply a tangle of vegetation floating on the water, but is a mass of decayed vegetation, papyrus roots and earth, much like peat in consistence and so compressed by the current that at places elephants can cross it safely. According to Willey, the thickness is only a few feet in the overflowed swampy area but increases abruptly to 15 and 20 feet in the channel. The close resemblance to the floating mat of more familiar types of sedges is evident. Were it not for the rapid current underneath, the whole channel would soon be filled by the more or less decayed material from the under side of the mat. But

²¹ D. A. Willey, "The Barrage of the Nile," *Nat. Geog. Mag.*, Vol. XXI., 1910, pp. 174, 184.

²² G. F. Wright, "Scientific Confirmations of Old Testament History," Oberlin, 1906, pp. 74-77.

these currents, even in great flood, are powerless against the mat; the river at some places is diverted into a false channel but at others it passes through a series of shallow lakes.

The groups of higher plants, contributing to production of peat, are for the most part those which prefer a soil containing organic acids formed during decomposition of vegetable matter. Some of them are provided with root modifications, enabling them to grow even when rooted in water-covered peat. Others, the ordinary conifers and deciduous trees of swamp areas, have no such modifications and grow only on the less moist portions. In case the water-level rise permanently so as to prevent aeration of the roots, the trees die; but mere accumulation of peat about the roots is not the direct cause of death, as it is proved abundantly by the existence of mighty trees in the western forests, the intervals between them showing several feet of peaty accumulation, in which young firs and scrubby oaks have grown from the seed. The great *Taxodium* and *Nyssa* are rooted directly in the water-covered peat, but aeration is secured by means of the "knees" and the arched roots which rise above the water surface. Aeration is as necessary to these trees as to the others and they can be drowned quite as easily as the junipers. Lowly forms of plant life make, as a rule, merely incidental contributions to peat, but under certain conditions they may accumulate in mass. Some forms of fresh water algæ are constituents of organic muds in pools or ponds, which so often become the foundation for peat, while occasionally one finds a layer of diatomaceous earth in or over the peat.

Classification of Peat.—The great economic importance of peat in some German states led early to close study of that material in all its phases and, of course, to classification, a differentiation of the varieties of peat and of the types of deposits. This work had been done in great part by the diggers before scientific students began, so that in all efforts at classification one finds greater or less use made of the popular terms. Zirkel²³ offered a grouping based on the character of the original materials;

Moostorf, derived from water-loving mosses, chiefly *Sphagnum*,

²³ F. Zirkel, "Lehrbuch der Petrographie," Bonn, 1866, Vol. I., p. 398.

Conferventorf, from free-swimming plants, Confervæ, Naiads, etc.,
Haidetorf, heath-peat from various heaths, largely *Erica tetralix*,
Holztorf, mostly from mouldered stems of trees,
Meertorf, from seaweeds, is of rare occurrence.

No one of these forms, except very rarely, is found as the mass of a bog, but all may be seen in the vertical section of a single deposit, indicating variations in conditions during growth. Zirkel gives also the ordinary terms designating difference in composition or structure;

Pechtorf is pitch black to brownish black and is apparently almost homogeneous; the plant remains are so changed as to be practically unrecognizable and the material, when dried, is very similar to Tertiary Pechkohle.

Rasentorf is yellowish brown or wood-brown and the remains of plants are distinct.

Fasertorf designates fibrous remains of plants, penetrating the Pechtorf.

Papiertorf is wood- or soot-brown, with the remains of plants little changed and in separable layers.

Torferde is a peaty earthy substance, friable and with few recognizable plant remains.

Baggertorf is a black-brown, pulp-like peat, obtained by dredging; it dries to a hard mass showing no vegetable structure.

Vitrioltorf contains much ferrous sulphate.

Some of these terms are unimportant, but others are of wide application, designating types which have been considered in all discussions. Von Gümbel²⁴ introduced a number of new terms, several of which have come into general use. For Pechtorf, he prefers Torfpechkohle, which is the Dopplerit of Haidinger; instead of Baggertorf, he suggests Specktorf and for Papiertorf, Blättertorf. For Fasertorf he would substitute Torffaserkohle; the former term is employed by several writers as descriptive of the felted mass of peat so that it is not definitive. The Conferventorf of Zirkel is

²⁴ C. W. v. Gümbel, "Beiträge zur Kenntniss der Texturverhältnisse der Mineralkohlen," *Sitz. d. k. Bayer. Akad. d. Wiss.*, 1883, pp. 128-134.

clearly the Dy-gyttja of H. von Post, the Lebertorf of Caspary, the Sapropel-mud of Potonié.

The salient characteristics of peat deposits are practically the same in all lands and the descriptive terms employed in different languages are almost equivalents; the German Hochmoor may be regarded as the Heathermoor of Scotland, the tourbière haute of Holland and France; the Niedermoor, Rasenmoor, Wiesenmoor and Grünlandmoor are but phases of the bogmeadows, morasses and tourbières basses of other lands; and the Waldmoor is a forested bog. Danish students long ago recognized the types under the names of Lyngmose, Svampmose or Hoermose, for the Hochmoor; Kjaermose or Engmose for the bogmeadows; and Skovmose for the wooded bog. Later German writers in some instances use Hochmoor, Flachmoor and Zwischenmoor. These several types, where the succession is normal, occur in definite relation to each other, marking successive stages in the growth of a deposit.

Growth of Peat Deposits.—The succession of stages in growth of a peat bog was determined in detail more than 100 years ago. All who have visited ponds in process of filling by peat are familiar with the oftentimes concentric bands of differing plant associations around the central water-area. This striking feature was emphasized by observers at a very early date, but a comparatively recent reassertion of the relation, as bearing on the formation of coal beds, seems to have come as a revelation to some, who had already discussed various questions relating to coal and coal beds. It is at least strange that the literature respecting peat appears to be unknown to so many geologists, since it is not confined to brief notes or to memoirs scattered through publications of learned societies, but includes elaborate treatises, some of them more than 100 years old. Many of these appear to be inaccessible in this country, but they have been cited so frequently by writers in Europe that one must believe them readily accessible there. Their existence has been ignored in discussion of coal relations, except where a casual reference enables a writer to show that the credit for an independent discovery does not belong to some later investigator. The facts

concerning growth of peat in water-basins have been known long time and the reports of observations were published widely.

In 1839, Palliardi²⁵ of Franzensbrunn, Bohemia, described a peat bog near that city, which had been dug for fuel during many years. It covers a space of one by three miles and is from 4 to 5 feet thick, occasionally reaching a maximum of 14 feet. The peat grows again in spaces whence it has been removed. In the second year, algæ appear and in the third there is a more definite vegetation, duckweed being prominent. During the fourth and fifth years, rushes, sedges and reeds form a floating cover, which the natives term the "cow paunch." Within ten to twelve years the surface is covered with *Erica*, *Vaccinum*, *Salix* and *Pinus*; and after thirty to forty years the peat may be cut again, if the water-supply have been constant and the cattle kept off. The deeper the deposit, the denser, more like brown coal and richer in bitumen the peat becomes.

In 1854, Vogt²⁶ recognized that the first stage is apt to be marked by accumulation of aquatic animals and plants, the latter mostly free algæ. Somewhat later, Heer²⁷ described the process in detail. In water, organic life begins with the algæ; even pure water, exposed to light and air, is full of little plants with boundless capacity for increase; they quickly appear in vast multitudes, which eventually sink to the bottom and, mingled with newer, higher forms, give a layer of organic matter. Then follow the floating mosses in great lawns with myriads of seeds, which, in spite of their minuteness, in time form a considerable mass of organic substance. Thus the way is prepared for life conditions of flowering plants, which arrive quickly. Bladderworts appear and the water-milfoils root in the soil; water-lilies spread out their leaves and cover the water; reeds press out from the shore; rushes and sedges form a thick complex of roots, which gradually extends over the whole and the water is concealed. This peat mass, constantly growing denser, draws moisture from below and in its soft, damp polster nest *Menyanthus*, *Andromeda* and

²⁵ Palliardi, in W. A. Lampadius, "Ueber den Schwartztorf und dessen chemische Eigenschaften," *Journ. f. pr. Chem.*, 1839, 2te Bd., pp. 16-18.

²⁶ C. Vogt, "Lehrbuch der Geologie," 2te Aufl., 1854, Bd. II., pp. 107, 108.

²⁷ O. Heer, "Die Schieferkohle von Utznach und Dürnten," Zurich, 1858, pp. 2-5.

heaths, which develop the peat foundation. The lake closed, forest vegetation, birch and fir, advances; the firs do not grow high, but they break off after attaining a certain height and weight, sinking into the soft material, where they are converted into peat, as is the less imposing vegetation. They are readily overturned by the wind, so that peat is crowded with birch and firs. Peat originates partly from mosses, partly from water-plants, partly from swamp-plants, especially the grasses and rushes, partly from woody plants. The hard parts change slowly while the softer parts become a pulpy mass enveloping the others. By climatic changes a Waldmoor may be converted into a Torfmoor and that again into a Waldmoor, giving a section in which a succession of forests is shown.

Three years later, von Post²⁸ grouped the successive deposits into mud (Gyttja), mud-peat (dytorf) and peat (torf), his conclusions being the outcome of more than 20 years' experience in the peat industry. In 1893, he presented a resumé of his studies as a lecture before the Upsala Institute. He had found that most of the Swedish peat mosses began in water-basins and that the bottom material, clay, mud or calcareous tufa, is sediment from more or less muddy water. A most important stratum is the brown earth, Dy in Swedish, which was formed by precipitation from the brown waters, containing huminic substances, quite analogous to the brown waters of rivers. These huminic substances, leached from accumulations on the land surface, are carried into the lakes by heavy rains. Spring water usually contains salts of calcium, iron and aluminum. When this enters the lake, huminic salts of slight solubility are precipitated, giving the brown layers, the Dy or Dy-jord. As this material goes down, it carries with it algæ (diatoms, etc.), fragments of mollusks, water insects and other débris, including excrement of animals. The passage to ordinary peat is gradual. Dy may be forming in the open portion of a lake while successive stages of bog-development are shown on the shores—and it may re-appear within the peat. Overflow, giving a constant rise of the water-level, may cause destruc-

²⁸ H. von Post, in *K. Vet. Akad. Handl.* (4), 1861, not seen by the writer; "The Formation of Peat-mosses with Especial Reference to the Theories of A. Blytt," *Bull. Geol. Inst. Univ. Upsala*, Vol. I., 1894, pp. 284-288.

tion of trees on a forested moor and bring about return of the peat moss condition.

Pokorny,²⁹ after exhaustive study of the Hungarian moors, presented a classification of the deposits and described the stages of growth. He recognized two general types, Hochmoors and Flachmoors, equivalent to the supra-aquatic and infra-aquatic of Lesquereux. The former include both forested and *Sphagnum* moors and are confined to higher land, while the Flachmoors, of many sorts and with many names, are on lower land and have an approximately level surface, contrasting with the convex surface of Hochmoors. The successive stages in growth of the Flachmoor are Hydrophyton, Rohrwald, Rohrwiese, Wiesen, Moorwiese, which correspond to those indicated by observers already cited. It is not necessary to make citations from the works by Rennie, Steenstrup, Senft or others of the earlier investigators in northern Europe, for their conclusions differ in wholly unimportant details from those of the later students. It is certain that the successive stages in development of a peat deposit were recognized more than three fourths of a century ago; since that time, the scheme has been modified only in detail.

In 1910, Potonié, using the Memel delta moor as the illustration, summarized the stages thus, in descending order:

Hochmoor,	{ Sea-climate Hochmoor, Hochmoor Vorzone, in part with <i>Arundo phragmites</i> ,
Zwischenmoor,	{ Conifer inner forest zone, Birch zone,
Flachmoor,	{ Alder moors, Reeds and rushes, shore zone,
Sapropel deposits.	

In a Hochmoor under a land climate, where the rainfall is less, the succession is completed by a heath stage, during which plants of the heath family take possession of the surface. This, Potonié suggests, may be regarded as the expiring stage of peat growth. If a boring were made through the Hochmoor and underlying materials

²⁹ A. Pokorny, "Untersuchungen über die Torfmoore Ungarns," *Sitz. Akad. Wiss. Wien*, Bd. XLIII., Abt. I., 1861, pp. 59-65, 86.

to the mineral floor, it would pass through beds of the several stages, each of which would be crossed in following the surface from the Hochmoor to the water's edge.

But one must always bear in mind that the order as given is not absolute; it is merely that observed where the filling of a basin has been continuous and undisturbed; any one or most of the stages may be omitted and any stage may be repeated. Local conditions control the succession. That in Michigan, as ascertained by Davis, is, ascending, (1) A deposit formed by *Chara* and floating algæ; (2) in the shallower water, *Potamogeton* followed by water-lilies; (3) next behind is the floating mat of sedges extending to a considerable distance from the shore; material from the under side of this mat accumulates near the shore and (4) shrubs and *Sphagnum* appear; (5) tamarack and spruce advance with ferns.

These stages are distinct around the open water and the trees are all rooted in the peat, which continues to accumulate while the trees are growing. *Sphagnum* is seen first after the surface rises to 2 inches above the water-level.

This general succession is that observed in peat deposits formed within gradually shallowing water-basins; it applies only locally to the great deposits formed on extensive plains.

The Lebertorf or Sapropel Stage.—Klaproth³⁰ appears to be the first describer of the material known in later time as Lebertorf. In 1807, he reported the chemical composition of a new combustible "fossil," which came from near Bartenstein in East Prussia. The detailed description of the substance leaves no room for doubt as to its relations. No later notice has been seen by the writer prior to those by Steenstrup and von Post.³¹ The former recognized a deposit of amorphous material which rests on the underclay of bogs, while the latter described the Dytorf, which usually underlies the peat. The substance was rediscovered by Caspary³² in 1870. He

³⁰ M. H. Klaproth, "Beiträge zur chemischen Kenntniss der Mineralkörper," Vol. IV., 1807, pp. 378, 379.

³¹ Steenstrup, summarized by Morlot, trans. in *Ann. Rep. Smithsonian Inst.*, 1861, pp. 304 ff.; H. von Post in Swedish Academy, 1861.

³² R. Caspary, "Lebertorf von Purpesseln," *Schrift. k. phys.-ökon. Ges. Königsberg*, 11ter. Jahrg. 1870, Sitz., pp. 22, 23.

had received from Purpesseln near Gumbinnen in East Prussia a peat, so peculiar that he visited the locality to learn its mode of occurrence. The moor was of moderate size and shaped like the figure 8, the broad portions being joined by a narrow strip. In the northern division, under a cover of one foot, he found Wiesentorf, 9 feet thick, black-brown and excellent fuel, containing many hard roots and fragments of stems. This overlies 5 feet of "Lebertorf," which is almost homogeneous, green-brown, very elastic, with coarse conchoidal fracture, with no trace of leaf structure and in appearance almost like animal liver. Occasionally, a root fragment occurs. The substance can be ground to powder under water.

When dried, Lebertorf is wholly different. It is grayish-black and almost invariably laminated, but the laminae are irregular, with no great extent, often as thin as paper and at times in meshes. It parts very slowly with its water; dried by exposure to the air, it is hard and, when cut with a knife, has brilliant black surface like jet. Under the microscope, fresh Lebertorf is found to consist of minute, light, grayish-brown granules with no trace of structure; bits of crustacean tests and well-preserved pollen of *Pinus sylvestris* are abundant; with them are occasional disintegrated parts of plants, showing cell structure. The southern portion of the moor seems to have only an insignificant trace of Lebertorf, the ordinary peat resting directly on the impermeable blue marly clay.

In 1883, von Gumbel²³ examined Lebertorf from Purpesseln and discovered that it has a felted structure. It contains some insect remains, leaves of grasses and mosses, many round balls, probably spores, and vast quantities of pollen grains, more than 1,000 to the cubic millimeter. Specimens from Kimmersdorf, near Gesterode, and from Doliewen, about 100 miles east from Königsberg, agree in that the cross section shows a uniformly dense mass composed of dull material like Boghead. The laminae are exceedingly thin and contain clear yellow particles and lens-like segregations of red-brown tint along with several thousand pollen grains to the cubic centimeter. He was impressed by the extraordinary resemblance to cannel and conceived that both substances originated in the same way.

²³ C. W. v. Gumbel, "Beiträge," etc., pp. 132, 133.

Früh³⁴ remarks that algæ are rare and merely accessory constituents of peat, but in some cases they are essential constituents. Material sent to him by F. E. Geinitz from the bottom layer of a moor at Gustrow was, when dry, hard, brown, homogeneous, with a greasy luster on the cut surface. It is laminated, consists in great part of well-preserved Chroococcaceæ with colonies of other forms of algæ, accompanied by pollen of conifers and *Corylus* as well as by chitinous fragments. He examined Lebertorf from Jakabau, received from Caspary, in which he found pollen and indeterminate remains of higher plants, embedded in a mass composed chiefly of algæ—Chroococcaceæ, Hydrodictyæ and diatoms. Lebertorf from Doliewen, received from Jentzsch of Königsberg, resembles the peat-shale or Torfschiefer from Gustrow and contains, along with pollen of *Corylus* and conifers, well-recognized colonies of *Macrocystis* as chief constituents. The Purpesseln material is similar in composition. Typical Lebertorf has been found at several places in Switzerland, where as elsewhere it consists chiefly of algæ, belonging to genera which are gelatinous. Diatomtorf belongs in this group; he had a specimen from Oldenburg containing 90 per cent. of diatoms.

Jentzsch³⁵ states that the Lebertorf of Caspary occurs at many places in Germany. Caspary recognized that it has a granular structure; v. Gümbel regarded the granules as exceedingly disintegrated plant remains, while Früh believed them to be algæ. Früh had examined a dried specimen from Doliewen. Jentzsch procured fresh material from that locality and sent it to him. Jentzsch and Caspary could find no evidence that Chroococcaceæ are present in this substance, structureless granules alone were recognized. All Lebertorfs show as chief constituents these roundish granules, which Caspary, v. Gümbel and Jentzsch regard merely as disintegrated plant material; associated with these are pollen from *Pinus* and catkins, bits of plant tissue, remains of crustaceans and often, but not always, diatoms and *Pediastrum*.

In a note appended to this paper, he gives the substance of a letter received from Früh respecting study of the fresh material

³⁴ J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883, pp. 20-24.

³⁵ A. Jentzsch, "Mikrostruktur des Torfs," *Schrift. k. ph.-ökon. Ges. Königsberg*, Jahrg. 24, 1883, pp. 47-53.

from Doliewen. This had convinced Fröh that the micrococcus-forms are not all Chroococcaceæ. He is certain, at all events, that Lebertorf is not genetically an algæ peat; the algæ are only accessory; pollen plays the chief rôle.

The elaborate microscopical examination of oil shales by Bertrand and Renault after 1890 led them to look upon those shales as accumulations of algæ and remains of other types carried down during precipitation of organic salts—an explanation very similar to that suggested by H. v. Post. These studies recalled similar studies of coal by Reinsch and led to farther study of Lebertorf. Potonié³⁶ made examinations in many localities, which he discussed at various times, publishing his final conclusions in 1910. The Lebertorf of Caspary, Faulschamm and plankton deposit of authors, is termed sapropellite by him. It contains diatoms, *Pediastrum* and other forms of algæ with pollen of *Pinus*, *Corylus*, *Alnus* and *Betula* along with remains of various aquatic animals. It accumulates rapidly in enclosed basins and it has rendered some German lakes so shallow that they are no longer navigable. Jeffrey³⁷ has observed that the bottom of lakes and ponds becomes covered with vegetable matter swept in by breezes or washed in by rains. This is finer in the deeper, less disturbed portions, but coarser in the shallower parts. In one of his figures, showing the finer type, one finds excrement of fish, snails or amphibia, mingled with pollen of conifers. In the other, showing the coarser material, there are merely remains of roots, leaves and other vegetable "flotsam and jetsam." It is noteworthy that he has found no trace of algæ in the lacustrine muck examined by him. Pollen grains and spores are the most important constituents.

The composition of Lebertorf is variable, certain constituents being more abundant at some localities than at others; but of all the constituents, pollen appears to be the most important; other remains are to be regarded almost as accessory, though always present.

Lebertorf cannot be recognized at all localities. Not infrequently it is absent in the lake deposits of north Germany as also in many of those in Sweden and Switzerland. Undoubtedly, the plankton

³⁶ H. Potonié, "Entstehung," etc., pp. 19-22.

³⁷ E. C. Jeffrey, "On the Composition and Qualities of Coal," *Econ. Geol.*, Vol. IX., 1914, p. 733, Figs. 151, 152.

conditions existed, but other growth seems to have been far in excess. Sapropelic deposits, as foundation for ordinary peat, appear to be practically wanting in the United States, as no reference is found in publications by Shaler and Harper, while Davis²⁸ observed them in only three of the many bogs examined by him in Michigan. The most noteworthy of these is that of the Algal lake; but the forms in that deposit are no longer thought to be algæ, their relations being still undetermined.

Lebertorf conditions may reappear at almost any time during the history of a peat bog. Sernander²⁹ long ago observed the lens-like structure characterizing portions of moors in Sweden, and Weber had called attention to the same feature in northern Germany. The study of peat deposits in Narke by the Geological Commission led to discovery of the causes and the results were published in 1905. The prevailing opinion had been that shoots of the sphagnum-carpet grow uninterruptedly upward, while the under parts die and are converted into peat. But the sphagnum-tips are killed very easily. On portions of the carpet, where such destruction has taken place, growth ceases, while the surrounding moss continues to grow, so that a depression results. Such depressions are very numerous and are due to various causes. One type, frequently observed in Heath- and Waldmoors, is caused by accumulation of offal from the plants; another is caused by surface growth of liverworts or certain forms of algæ; while a third comes from fires, footsteps or other accidents. As the surrounding *Sphagnum* continues to grow, the depressed spots become filled with water; plants growing on the surface are killed and a Dy-like deposit covers the bottom. The ordinary process of filling follows, sphagnum invades the pool and eventually fills it. The depressions sometimes increase by transgression and attain considerable size. An illustrative section, given by Sernander on his Plate 3, shows that interruptions of this kind are of frequent occurrence. Similar depressions are familiar in bogs of all sorts.

In many cases, especially where the water is calcareous, this

²⁸ C. A. Davis, "Peat," pp. 203, 247, 267.

²⁹ R. Sernander, "Guide to Excursions," *Cong. Geol. Int.*, XI., Excursion A7, p. 25.

plankton deposit of bacteria, algæ and especially pollen and spores is concealed in the accumulation of marl from *Chara* and mollusks. At best, it is characteristic only of filled water-basins; it occurs rarely in the great deposits originating on broad coastal or river plains. This is not to assert the total absence of such material. Those great deposits frequently were due to union of numerous smaller ones, each of which filled a depression of moderate extent and afterward expanded by transgression on the plain. Lebertorf may form the floor in the original depressions, though it may be thin, owing to rapid invasion by the plants giving normal peat. In the other condition, where swamps were caused by obstructed drainage, Lebertorf-forming agencies no doubt existed, but they did not predominate. Indeed, those agencies are always present, except during periods of interrupted growth, due to dryness, as one may learn by descriptions of almost all bogs, which show that freshwater algæ along with pollen and spores are accessory constituents at all horizons. Whenever a pond is formed in any considerable deposit, such as Dismal Swamp, originally covering not less than 1,500 square miles, the conditions are prepared for formation of a Lebertorf lens.

The Succeeding Stages Vary.—The earlier studies were made almost wholly upon peat deposits filling former water-basins, which had escaped covering and which had had a, so to say, continuous history from a very early period. When the process of filling was uninterrupted save by variations in temperature or moisture, the normal succession may be shown by the bogs in a great area, as in most of Sweden, north Germany and the British Isles. But where the origin was different, a wholly dissimilar section may be found. Geikie, in describing the moors of Scotland, says that they often mark the sites of lakes and ponds, but at times they cover the ruins of ancient forests. When the forest was overthrown, drainage was intercepted, stagnant swamps were formed and water-mosses took root. He refers to several illustrative instances. In the Forest of Mar, large trunks of Scotch fir, which fell from age and decay, were soon immured in peat, formed partly from decay of their perishing leaves and branches and partly from the growth of *Sphagnum* and

other marsh plants. On Loch Brown, the peat cover was completed over the site of a decayed forest in less than 50 years. In 1756, the Wood of Drumlanrig was blown down and experienced a similar fate.⁴⁰

Miller⁴¹ has cited the Earl of Cromarty's description of peat growth in central Ross-shire. When very young, the earl had observed a wood of very ancient trees, doddered and mossgrown, evidently passing through the last stages of decay. Many years later, he passed through the same district and found that the wood had disappeared, while the heathy hollow was occupied by a green stagnant morass. In his old age, he revisited the locality; the surface was irregular and pitted, for the highlanders were digging peat in a stratum several feet deep. The aged forest had been replaced with an extensive peat moss.

The sphagnum-stage is not rarely the first. Dachnowski⁴² found *Sphagnum* growing in Ohio on wet sand, where it formed tussocks often more than 4 feet high. This matter will be considered in another connection.

It may be well to note, parenthetically, some other observations by Dachnowski. Davis had recognized in Michigan that *Sphagnum* is indifferent to calcareous salts, growing as well where the water is hard as where it is soft. In Ohio, the nature and quantity of the mineral salts seem to be unimportant, since the heath-sphagnum meadows are abundant in counties where they rest on limestone, while in one locality *Sphagnum* grows in profusion near springs charged with calcium carbonate; this plant in Ohio as in Michigan is indifferent to that salt, for Dachnowski found it abundant in one locality and wanting at another, the conditions being the same in both. Deficiency in mineral matter does not prevent growth of trees on peat; they grow well on the floating mat of heath-sphagnum and in places where the peat is 30 feet thick. In Ohio, the heath-association does not mark the final stage, for it is followed by the bog shrubs. The final stage is marked by the bog-forest association,

⁴⁰ A. Geikie, "The Scenery of Scotland," 2d ed., London, 1887, pp. 388-392.

⁴¹ H. Miller, "The Old Red Sandstone," Boston, 1860, p. 174.

⁴² A. Dachnowski, "Peat Deposits of Ohio," Geol. Surv. Ohio, Bull. 16, 1912, pp. 224-256.

of which tamarack (*Larix laricina*) and arbor vitæ (*Thuja occidentalis*) are among the first to invade the surface. When bog conditions have disappeared and the surface has become covered with mould, deciduous trees advance and crowd out the conifers. As the mould-cover is very thin and the wet peat is reached very quickly, the roots of this forest group rarely extend downward more than a foot, but they spread out in all directions, as do those of the conifers, thus giving stability.

Structure and Constituents of Peat Deposits.—An intimate examination of a peat deposit leads to conviction that the process of accumulation may not be so simple as is indicated in the preceding generalized paragraphs. There are many modifying conditions.

A peat bog shows, speaking generally, a thin layer of living plants on top, under which the vegetable matter becomes more and more disintegrated downward until, toward the bottom, the greatest part shows no vegetable structure to the unaided eye and the mass consists of felted stuff cemented by a humus-like substance. This cement is removable easily by weak solution of caustic potash and the dried residue tends to fall to a powder. The change downward is not, however, always in increasing ratio.

A peat deposit is rarely continuous from bottom to top, but is commonly divided at irregular distances by partings of one sort or another. These may be thin, consisting of finely divided mineral matter holding a charcoal-like substance, Torffaserkohle of v. Gümbel, or they may be thicker and composed of sand, clay or other transported matter. The thickness of individual partings varies greatly, so that the intervals between the several benches of the deposit may increase or decrease. Loric's⁴³ observations in Holland, Belgium and north France make this variation sufficiently evident. The benches themselves differ in peculiarities of the peat and in character of the ash, as one would suppose in view of the different plant-associations marking the several stages of growth.

The opinion has been expressed that a layer of organic material is essential as prerequisite to formation of a peat deposit, and the assertion has been made that, in any event, a Hochmoor with its

⁴³ J. Loric, "Les dunes intérieures," etc., *Arch. Mus. Teyler*, II., Vol. III., pp. 424-427, 444.

mosses cannot begin on inorganic material. This material can hardly be determined satisfactorily either positively or negatively, as the thickness of the organic layer is regarded as immaterial, one author holding that it may be so thin as to be unrecognizable, while he still insists that it must be present. There can be no doubt that, when a Hochmoor increases by transgression, it is likely to rest in part upon inorganic material. Rohhumus on bare rock, the sphagnum-peat described by Dachnowski and some instances to be noticed on a later page appear to indicate that a moss peat may begin on inorganic surfaces. At the same time, it is beyond all question that, of deposits originating on the surface of plains, a very considerable proportion began on forested areas, where the litter afforded excellent base for peat growth after the drainage had been impeded. Shaler, many years ago, referred to transgressing bogs in New England, which invaded forests and eventually killed even the water-loving trees. Lewis⁴⁴ says that in the lowland mosses of Wigtonshire, Scotland, the till surrounding the original area of obstructed drainage carried birch and *Calluna*, which were replaced gradually by hazel and alder. In these deposits, *Betula* is abundant even on the floor. Sanford regards the Everglades of Florida as due chiefly to impeded drainage. Peat operators have long known that if the bog be stripped clean to the underclay, peat growth begins very much more slowly than when a thin cover of vegetable matter has been left on the clay.

The partings in peat deposits, when consisting of clay, sand or marl, indicate subsidence or flooding. They may be so numerous as to render the mass worthless, the laminations of peat and foreign matter being alike thin; or there may be alternations of fairly clean peat with layers of intimately mingled organic and inorganic materials. The former indicate very frequent floodings, while the latter tell of a long period of subsidence interrupted by longer or shorter periods of comparative stability. A good illustration of the latter condition is that given by Debray⁴⁵ in his description of a

⁴⁴ F. J. Lewis, "The Plant Remains in the Scottish Peat Mosses," Pt. I., *Trans. Roy. Soc. Edinb.*, Vol. XLI., 1906, pp. 699-722.

⁴⁵ L. Debray, "Étude géologique et archéologique de quelques tourbières

section in the valley of the Somme. The deposit is 8 feet thick in 13 wholly distinct benches, varying in thickness from one third to one meter. Four benches, aggregating 2 meters, are of excellent peat, but the others are, in several cases, little better than carbonaceous shale; the ash is calcareous. Similar illustrations are to be found in the American treatises.

In areas where floodings of muddy water are wanting and where climatal variations show little change from year to year, there may be no benches and the mass may be continuous from bottom to top. Johnson⁴⁶ has described a peat deposit, which shows about 15 feet of sphagnum-peat, practically continuous. Cook,⁴⁷ in discussing the bogs of New Jersey, states that the peat is so crowded with logs of *Chamaecyparis* that one has difficulty in thrusting a sounding rod to the bottom. The condition is the same throughout, even where the peat is 13 feet thick; the Waldmoor growth was uninterrupted. A similar story is told by the cypress swamps. R. M. Harper and others have shown that, in the cypress swamps of Florida, the peat is so filled with logs and woody roots as to be without commercial value. Lyell's⁴⁸ statements respecting the cypress swamps of the Mississippi region are in similar terms; for he says that the contractor, in excavating for foundations of the New Orleans gas works, soon discovered that he had to deal not with silt but with buried timber; the diggers were replaced with expert axemen. The cypress and other trees were "superimposed one upon the other, in an upright position, with their roots as they grew." The State Surveyor reported that, in digging the great canal from Lake Ponchartrain, a cypress swamp was cut, which had filled gradually, "for three tiers of stumps in the nine feet, some of them very old, ranged one above the other; and some of the stumps must have rotted away to the level of the ground in the swamp before the upper ones grew over them." It should be said that the whole du litoral Flamand et du Département de la Somme," *Mem. Soc. Sci. Lille*, Vol. XI., 1872, pp. 471, 472, 475-478.

⁴⁶ D. W. Johnson, "The Shoreline of Cascumpeque Harbor, Prince Edward Island," *Geogr. Journ.*, 1913, pp. 152-164.

⁴⁷ G. H. Cook, "Geology of New Jersey," 1868, pp. 301, 355, 360, 484.

⁴⁸ C. Lyell, "Second Visit to the United States of North America," London, 1850, Vol. II., pp. 136, 137.

delta region of the Mississippi is subject to frequent floodings, but, in a great part of the area, the dense "cane brakes" act as filters, so that the water is freed from its load of silt and continuity of swamp growth is uninterrupted.

There are serious interruptions in the growth, which are not due to flooding or to merely local variations in the water-level but rather to widespread changes in conditions. Benches in thick deposits frequently appear to represent cycles of deposition and these often are separated by thin partings of exceedingly fine mineral matter, containing more or less of fibrous material resembling the mineral charcoal of ordinary coal. Such partings were explained long ago by Lesquereux as due to a period of dryness, when the peat ceased to grow and the surface was destroyed by oxidation to a greater or less extent. The period of exposure may be brief or it may be long continued. A. Geikie and Lewis have made clear that peat forms now in only exceptional localities within Scotland, as the climate has become less moist; and Skertchly asserts that peat is no longer forming in the Fenland of England, save in a dark narrow valley of Suffolk. The peat is wasting in those areas. Similar statements come from other parts of northern Europe. Leaving out of consideration *Taxodium*, *Nyssa*, certain palms and the trees of the Kampar areas, it is certain that most of the trees growing on peat do not thrive when the material is very wet. Some, it is true, show a notable degree of adaptation. C. A. Davis saw in Michigan a birch in healthy condition, though its roots had been covered with water during more than a year; and there are other types which do well if only the water cover be absent during a considerable part of growing season: the tamarack at times takes root far out on the floating bog, but it grows slowly as do other trees which accompany it. One may learn much respecting changing conditions during the growth of a peat deposit by noting the distribution of trees.

Zincken⁴⁹ cites Hartig as saying that in the "rothe Bruche" on the Harz there occur in the lowest 5 feet of the 39 to 40 feet thick Hochmoor, firs with stems 18 inches thick. Higher, is a layer with large pines, on which is another with smaller plants of the same

⁴⁹ C. Zincken, "Die Physiographie der Braunkohle," Hannover, 1867, p. 38.

genus, while in the next layer the forms are stunted. Both firs and pines are wanting in the upper portion of the mass. Sernander and Kjellmark⁵⁰ discovered that in northern Nericke, Sweden, the succession is (1) Living peat; (2) sphagnum-peat; (3) bed of stumps and roots; (4) sphagnum-peat, passing downward into peat composed chiefly of *Phragmites* and *Equisetum*. The stump layer has birches with needles and bark of *Picea abies*, *Pinus sylvestris* with fruits, seeds and leaves of other plants.

In the Harz locality, increasing wetness destroyed the trees; in Nericke, trees advanced when the moisture decreased, only to be destroyed when once more the moisture increased.

According to Poole,⁵¹ the great turbary, known as the South Marsh, is double. The upper part is 7 to 8 feet thick and is worked for use as fuel; the lower portion, of about the same thickness, has on its surface everywhere the stumps and roots of trees, standing as they grew. Woodward states that the peat is composed mostly of sedges, so that it is clear that the restoration of marsh conditions led to destruction of the forest which had grown on the bog surface. Skertchly⁵² recognized five successive forests in the peat of Wood fen near Ely. Number 1, at the bottom, is of oak and the trees are rooted in the Kimmeridge Clay; Number 2 is at an average distance of 2 feet above the other and consists of yews and oaks, the lower forest having perished before this began, as roots of Number 2 sometimes rest on stumps of Number 1; at 3 feet higher, are the remains of another forest, all firs, and another is just above that; while immediately below the present surface is still another, resembling the modern trees of the region. There were five successive forests, of which all except the first were rooted in the peat. As Skertchly remarks, it is evident that, while in general the climate of the Fenland may have favored peat making, still there were intervals when peat was formed, if at all, in very limited areas, the other portions being

⁵⁰ R. Sernander und K. Kjellmark, "Eine Torfmooruntersuchung aus dem nördlichen Nericke," *Bull. Geol. Inst. Upsala*, Vol. II., 1896, pp. 321, 324.

⁵¹ G. S. Poole, cited by H. B. Woodward, in "Geology of Eastern Somerset," *Mem. Geol. Surv. London*, 1876, pp. 146, 156.

⁵² S. B. J. Skertchly, "The Geology of the Fenland," pp. 130, 151, 165, 168, 169.

invaded by forest. The non-peat-making intervals must have lasted more than 150 years, as appears from the size of the trees. The region is now passing through another dry period and the peat bogs are not increasing. De la Beche⁵³ has referred to the Drunkelin bog in Donegal, Ireland, as affording a striking illustration of interruption in accumulation of peat. At 16 feet below the surface and resting on 15 feet of peat, a house was reached 12 feet square, 9 feet high and constructed wholly of oak. When the peat had been removed from about the house, a paved pathway was disclosed, leading to a hearthstone covered with ashes. Near the house were stumps of oak trees, which evidently were growing when the house was inhabited. A layer of sand had been spread over the surface before the little building was erected. This pause in growth of the deposit was of sufficiently long duration to permit forest growth and to invite habitation. It was followed by return of swamp conditions, during which 16 feet of peat accumulated.

Geikie⁵⁴ has recorded several cases of which only two need be recalled here. At Strathcluony, three tiers of Scotch firs were seen, separated by layers of peat. Several tiers were exposed in a railway cutting across the Big Moss, one of standing firs with branching roots at 6 feet below the surface, a second at 12 and a third at 16 feet below the surface; so that, counting the present surface growth, four forests have grown there since the bog-making began; that is to say, the swamp conditions have been interrupted four times by periods of lessened moisture, the last being the present. The preceding three were succeeded by periods of wetness during which peat-making proceeded vigorously. It must not be supposed that even in the drier periods accumulation of peat ceased wholly. It has been known a long time that the offal of conifers can accumulate as peat. Reinsch⁵⁵ says that in the Fichtelgebirge needles of Fichten, Tannen and Föhren are important as peat-making material and that in time they accumulate in such quantity that a quaking bog is the result. One must insist here that the mere accumulation of peaty materials around and

⁵³ H. T. de la Beche, "The Geological Observer," Amer. ed., 1851, p. 134.

⁵⁴ J. Geikie, "The Great Ice Age," 3d ed., London, 1895, pp. 286-293, 303.

⁵⁵ H. Reinsch, "Ueber den Torf des Fichtelgebirges," *Journ. f. pr. Chem.*, Bd. XVI., 1839, p. 486.

between the trees was not the direct cause of their destruction; but accumulation in an increasingly moist climate might well contribute indirectly by retention of moisture and thereby bringing about the condition in which proper aeration of the roots could not take place.

Lesquereux, Heer, Geikie, Grand'Eury and others have shown by sections in Britain and central Europe this alternation of swamp and forest conditions, while Steenstrup, Blytt, von Post, Andersson, Sernander and others have made the matter abundantly clear for the Scandinavian areas.⁵⁶

The causes of these alterations have been subject of much discussion, as they are among the most striking features of peat deposits. Andersson⁵⁷ maintains that the presence of tree stumps in a bog is not necessarily evidence of actual change in climate; that can be explained by the ability of peat bogs to invade forests and to convert them into swamps, as has been proved by several Swedish observers. But this familiar fact can explain only the presence of trees rooted in the underclay; it does not explain the presence of a forest layer with its roots wholly enclosed in the peat. This indicates invasion of the swamp area by the forest. A change in direction or extent of drainage might answer well as explanation of local appearance of trees, for only a slight lowering of the water-level would suffice. But changes in drainage or the encroachment by swamps, while accounting well for local variations in a swamp, great or small, cannot suffice as explanation of widespread variation appearing almost contemporaneously in immense areas. Some general cause must be sought. Blytt and von Post have presented incontrovertible evidence of alternations in climatal conditions throughout Scandinavia; Lewis has done the same for Scotland as J. Geikie has done for a wide area; while Schreiber,⁵⁸ after detailed study within the province of Salzburg, showed that the variations in bog life were associated with climatal changes involving migration of the snow-line in the Alpine regions.

⁵⁶ See "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 604-613.

⁵⁷ G. Andersson, "Studier öfver Finlands torfmosser och fossila kvartarflora," *Bull. Com. Geol. de Finlande*, No. 8, 1898, p. 186.

⁵⁸ H. Schreiber, "Vergletscherung und Moorbildung in Salzburg." Separate from *Oester.-Moorzeitschr.*, Staab, 1912, pp. 14, 15.

Preservation of Vegetable Matter in Bogs.—The chemical processes leading to conversion of plant matter into peat do not fall within the scope of the present inquiry, but some features must be considered, though without reference to their causes.

Even a casual examination is enough to convince the observer that these processes do not attack all plants or all portions of a plant equally. Bunbury⁵⁹ says that the peat in a great bog was found to be merely a black mud, so decomposed as to show no vegetable structure; but at 15 feet down in this mud there was found a horizontal layer, 2 to 6 inches thick, of compressed, undecayed moss, *Hypnum fluitans*, without admixture of other material. The peat below this layer is like that above it. Skertchly⁶⁰ notes a similar case. In the turbary near Ely, the peat is digged to a depth of 4 feet. At the top for about a foot it is chestnut brown and not bedded; this is succeeded by 3 feet of black peat, which is bedded, contains roots of reeds, flags, etc., but in the mass shows vegetable structure obscurely; at the bottom is a layer, almost wholly *Hypnum*, which dries to a yellow tint and preserves the vegetable structure. It is well known that the soft parts of plants disappear quickly to become the pulp, in which the harder parts are embedded and of which they themselves eventually become part.

The bark of trees is resistant, even that of trees whose wood decays rapidly. Darwin⁶¹ remarks that in the valleys of Tierra del Fuego, it was scarcely possible to crawl along, the way being barricaded by great mouldering trunks, which had fallen in every direction. When passing over these natural bridges, one's course was often arrested by sinking knee-deep into the rotten wood; at other times, when attempting to lean against a firm tree, one was startled by finding a mass of decayed matter, ready to fall at the slightest touch. There are few living in the temperate zone who have not been startled in like manner by the crashing of a log on which they had set themselves in the woods. The bark had remained sound

⁵⁹ C. J. F. Bunbury, "Notice of Some Appearances Observed in Draining a Mere," *Quart. Journ. Geol. Soc.*, Vol. 12, 1856, pp. 355, 356.

⁶⁰ S. B. J. Skertchly, "Geology of the Fenland," p. 135.

⁶¹ C. Darwin, "Journal of Researches," Amer. ed., New York, 1846, Vol. I., p. 302; Vol. II., p. 44.

though the wood was wasting away. The rate of decay is indefinite. Darwin estimated that in the neighborhood of Valdivia in Chili, a stump of 18 inches diameter would be changed into a heap of mould within 30 years; but in Java, Koorders, cited by Potonié, saw much fallen timber, decades old yet still in condition for export. In the northern part of the United States, stumps of maples, elms and spruces, 18 inches to 2 feet or more in diameter, are often sound enough after 25 years of exposure to require blasting for their removal. The wood of oaks and conifers is especially resistant, yet even those may go rapidly. Lesquereux,⁶² in referring to the sunken forest of Drummond lake in the Dismal Swamp, says that standing stumps of bald cypress (*Taxodium distichum*) are decaying so that many of them are hollow. Fruits and leaves of trees, falling into the water and drifting, are arrested by the hollows of these trees and fill them almost completely. De la Beche,⁶³ in discussing the decay of plants, observes that "this kind of decay is still more instructive where upright stems of plants in tropical low grounds, liable to floods, retain their outside portions sufficiently long to have their inside hollows partially or wholly filled with leaves and mud or sand, the whole low ground silting up, so that sands, silt and mud accumulate around these stems, entombing them in upright position, without tops, though their roots retain their original extension." Potonié, in 1895, called attention to the fact that hollow alder stumps in West Prussia swamps, exposed to high water, are filled with sand even to the roots, so that they must be cleaned out before the axe is applied.

Generally speaking, the wood of deciduous trees decays rapidly while that of conifers changes slowly. Lesquereux, on the page preceding that just cited, records that in Denmark, about 20 miles below Copenhagen, there is an extensive grassy plain with one foot of humus as the soil. Underlying that is a bed of peat-like material, 6 feet thick, composed wholly of closely packed, flattened birch bark. This, free from earthy matter, is cut out and dried in long rolls. The woody part of the stems, now nearly fluid or transformed into a very soft yellow mud, is at the bottom of the deposit, whence it is

⁶² L. Lesquereux, "Geology of Pennsylvania," 1858, p. 847.

⁶³ H. T. de la Beche, "Geological Observer," p. 133.

removed in buckets and dried for fuel. Debray⁶⁴ found plant remains resembling burnt straw within the peat,—the Torffaserkohle of v. Gümbel, a by no means rare occurrence in peat. Birch bark retains its silvery color; the wood of oak is hard and black, but other woods are soft, yellowish and shrink much in drying. Debray observed in this peat of the Somme valley, some shrubs in an inverted position, which he very properly regards as proof that they did not grow where found. Skertchly⁶⁵ reports that the birches of Ruskinton fen are represented only by their papery bark, which retains its silvery luster; the bark of elms is preserved but the wood is rotten like touchwood; wood of oaks, always stained black, is often sound enough to be used for gates and fencing posts, though usually fit only for fuel; but the wood of conifers is little changed, that of yews retains the peculiar brown color, while that of firs is as white and sound as if from living trees and the odor of turpentine is distinct when the wood is cut. The *Chamæcyparis* of the New Jersey peat is so good that much of it can be used in building and in cabinet work; the preservation of oak in bogs of Ireland and Switzerland is familiar to all who have visited those countries.

The wood in peat deposits does not always represent material dead or wasted prior to burial. The logs and stumps in the lower portion may be remains of a forest destroyed by advance of the swamp, but that is not necessarily the case with such remains higher in the peat. Trees growing on the surface of peat are uprooted readily by the wind as they have an unstable soil; if the forest be not too dense, such overturned stems sink into the pulpy mass and the deposit becomes crowded with stems, embedded before decay had set in.

Thus one finds logs, in all stages of decomposition, embedded in pulpy matter, derived largely from the soft parts of plants and holding also the waste of various woods as well as abundant pollen, spores, bacteria, fungi and freshwater algæ.

Effect of Pressure on Peat.—Many years ago Lesquereux asserted that peat has a laminated structure and since his time other observers have referred to laminated peat; but this lamination is not

⁶⁴ L. Debray, "Étude Géologique," etc., pp. 445, 449, 450.

⁶⁵ "Fenland," pp. 160, 161.

so distinct in ordinary peat as to attract the attention of a casual observer. Under pressure, however, the structure is well-defined.

Spring⁶⁶ tested the effect of compression on Holland and Belgian peat, mature but retaining much material showing organic structure. Under pressure of 6,000 atmospheres, this was changed into a black, brilliant block, with all the physical aspect of a coal; the fractured surface, as seen under the glass, was distinctly laminated, while evidence of organic texture had disappeared. Under this pressure, the peat became plastic and ran out into the chinks of the compressor. Thoroughly matured peat, after this compression, does not absorb water and does not return to its original form. von Gumbel⁶⁷ subjected spongy sphagnum-peat to a pressure of 6,000 atmospheres, by which it was rendered apparently homogeneous and as hard as pasteboard. A pressure of 20,000 atmospheres increased the density to that of sole leather. In each case, lamination was distinct and the streak was lustrous, but when placed in water, the material swelled to almost the original bulk. Evidently, pressure of brief duration suffices to produce permanent physical change in well-matured peat though not in the immature substance. But one is not dependent on laboratory results; the experiment has been performed in nature many times and on a grand scale.

Forchhammer,⁶⁸ in his descriptions of dunes on the Baltic coast, of Denmark, states that among those dunes are numerous lakes and ponds characterized by abundant vegetation and by formation of peat. When an unusual storm passes over the dune, sand is blown into the ponds and puts an end to growth of peat. This buried peat, known as Martörv, is exposed when currents cut away the coast. The phenomenon is not confined to the mainland; on the north side of Seeland, there was a pernicious stretch of quicksand early in the eighteenth century but, before 1760, it had become

⁶⁶ W. Spring, "Recherches sur la propriété que possèdent les corps solides de se souder par action de la pression," *Bull. Acad. Roy. Belg.*, II., Vol. 49, 1880, pp. 367, 368.

⁶⁷ "Beiträge," etc., pp. 127, 128.

⁶⁸ G. Forchhammer, "Geognostische Studien am Meeres-Ufer," *Neues Jahrbuch*, Jahrg. 1841, citations from pp. 13, 14.

watered and covered with a dense forest of fir. On the border of the dune, the sand covered part of a peat-moor, where it had stopped growth while accumulation continued unchecked on the uncovered portion. Peat from the latter does not differ from that of bogs in the neighborhood, but that from the sand-covered portion has been changed into a wholly different substance. Ordinary Moor-torf, dried, weighs from 16 to 20 pounds per cubic foot, but that which has been compressed by the dune weighs 78 pounds. In ordinary peat, dried, one finds scarcely any trace of layers, but this compressed peat is almost shale-like in lamination. The Seeland peat is formed mostly of offal from a forest vegetation, but in hand specimens one cannot distinguish it from brown coal.

v. Gümbel in 1883 found that the Martörv has alternating bright and dull laminae, the bright portions consisting chiefly of ribs and hard parts of grass leaves with admixture of other parts, pollen, etc. He thought that it bears much resemblance to Lebertorf, but it is clearly of different origin. One would surmise from the conditions that this Martörv contains both mature and immature peat. The observations by Jentzsch are confirmatory. He remarks that the Martörv found near Rixhoft in East Prussia is derived without doubt from the Bielawe and other moors, that it is compressed material from underneath the dunes, which now separate those moors. Nilson⁶⁹ has described a vast gravel deposit which follows the Baltic coast of Sweden for a long distance beyond Ystad and, at various places, rests on peat.

This material is similar in composition to the recent peat of Sweden.

Lesquereux's⁷⁰ description of conditions in the valley of the Locle in Switzerland is equally to the point. On the side of the valley, under a heavy bed of marl, he found 3 inches of compressed material, hard, fragile and with brilliant fracture; lower down the slope, where the marl is but 4 feet thick now, the deposit is 6 to

⁶⁹ Nilson, cited by J. Geikie, "Prehistoric Europe," p. 473.

"The peat under this stone wall is so compressed that, when dry, it is almost as hard as brown coal; the trees also are, like the layers of coal, pressed together, and when a fir chip is broken, it is found to be black and shining in the cross-section, all the result of great pressure and age."

⁷⁰ L. Lesquereux, "Quelques recherches sur les marais tourbeux," *Mem. Soc. Sci. Nat. Neuchatel*, Vol. III., 1845, pp. 95, 127.

7 inches thick and retains some peat-like features, but is a passage from the lignite of the border to the peat of the open valley, which has been growing continuously, so that it is now 8 feet thick. In another connection, he remarks that some deposits of lignite are surrounded by peat. Goeppert's⁷¹ observation is very similar. A deposit of peat was found in the low part of a valley near Helvetihof in Upper Silesia. On both sides of the valley, a portion of the deposit is covered with 2 to 10 feet of soil and sand beds, under which the peat has been changed into a distinctly laminated, hard black mass, almost like stone coal; whereas the peat in the open valley, uncompressed, has the usual brown color and comparatively loose structure.

Preservation of Peat Deposits.—The surface of a dead bog is often irregular as though it were wasting away; the peat-cover of a drained area, under cultivation, disappears within a few years as ploughing exposes more and more of it to oxidation, drying and the winds. A casual observer of the "hag" region of Scotland feels justified in believing that peat is formed only to decay and that little of it will survive to reach a more advanced stage of transformation. This is the conclusion reached by an eminent student of coal problems and his opinion appears to have been accepted as fact by several authors. But the conclusion cannot be accepted as final; it seems to be based on incomplete observation or on lack of familiarity with conditions in great areas. The process of removal, where man does not interfere, is slow, because peat, with its felted structure and its obstinate retention of water, offers great resistance to erosion. A very thin cover of fresh peat protects itself and the underlying rock from removal. The effect of oxidation is not rapid, as it is necessarily superficial, circulation of air in the drying peat being confined to the newer portion.

Lowering of the water-level does not mean that the surface is to become dry and pulverulent, to be swept away by the wind. In most cases, that lowering of the level leads to invasion by plants which cannot endure wet conditions, to the growth of a rather dense cover of vegetation which, by its accumulating offal, protects the

⁷¹ H. B. Goeppert, "Abhandlung eingesandt als Antwort auf die preisfrage," etc., Amsterdam, 1848, pp. 104, 105.

peat already formed and adds to the mass. As soon as local or general conditions again become favorable, peat growth in the ordinary way would be resumed and the invading vegetation would be killed. The record of alternating wet and dry periods is distinct in very many deposits which offer no evidence of serious waste during the passage from one to the other. Some of the less moist periods must have continued for centuries, if one may judge from the age of rooted trees in the forest layers. Certainly the desiccation process did not extend deeply, for the roots of trees in those layers are spread horizontally in shallow depth, as though avoiding the wet peat below, just as do the roots of the invading forest trees now.

It is wholly possible that comparatively little of the peat now forming will reach a later stage in transformation; the agricultural importance of peaty lands is understood, as is also the method for their preservation, so that the work of drainage and reclamation will be more and more extensive in the future. But with that this study is not concerned. The questions involved deal with conditions prior to man's interference with nature's operations. The evidence all encourages the belief that a very great part of the older peat has been protected and that the peat now forming in uninhabited regions will be protected in like manner, to become a genuinely fossil fuel. Buried peat deposits are known throughout the world.

Forchhammer, Jentzsch, F. E. Geinitz and others have described dune-covered bogs along the Baltic shores and C. A. Davis has referred to the same condition in Michigan. The process continues in those regions. One finds frequent notes respecting submerged bogs, often continuous with living bogs on the shore, as though the swamp had advanced up the surface during the subsidence. In some localities, portions of the submerged bog are already covered with materials from the land, while other portions are still free from cover; in such cases, the overlying deposit should contain marine forms. At times, the influx of inorganic matter continues until land conditions, have been restored and the peat extends over the new surface. Borings in northwestern Europe pass through a succession of peat bogs separated by sand or clay. Similar relations are exposed in deep excavations and occasionally in uplifted areas.

J. Geikie⁷² has given numerous instances of submerged deposits on the coast of Scotland. Farther inland, in the Carse lands on both sides of that country, deeply buried deposits have been exposed by the rivers. The River Tay has cut its channel down to a peat bog, now forming the river bed and underlying about 17 feet of alluvial material, which near the top contains cockles, mussels and other marine forms. In some parts of the wide Carse area, this extensive deposit rests on alluvial sands but in others on marine clays. The peat is much compressed and splits readily into laminæ, on whose surfaces are small seeds and wing cases of insects. As a rule, it is marked off sharply from the overlying clay and silt, but, at times, it is covered with vegetable debris which was drifted in from places higher up in the valley. Skertchly⁷³ found that on the Isle of Ely the peat underlies 4 to 8 feet of silt and clay and rests on clay, both roof and floor being marine, the peat marking an interruption in deposition of the clays. Several peat beds are within 12 feet; the lowest, 18 inches thick, is normal, black and clean; but the higher peats are irregular and impure, mingled with clay, showing the contests between plants and muddy water. Travis⁷⁴ has described a case of marine association, which shows also a by no means unusual relation of the beds. The Seaforth Dock excavation, 40 feet deep, 180 wide and 900 long, exposes two beds of peat. The lower, 18 to 24 inches thick, rests on gray sand and is shown for about 280 feet. At 5 to 10 feet higher, the interval being filled with *Strobicularia* clay, is the upper bed, 12 inches thick, which is exposed for 480 feet. It overlaps the lower one, which thins out. The peat in both bands is firm, woody, with occasional fragments of bark and twigs, but it contains no stumps or trunks of trees.

Lorié has recorded a great number of borings in Holland, which illustrate the succession of buried peat beds, separated by sands deposited beneath the sea. Rutot has given records showing peat beds intercalated in marine sediments on the coast of Belgium.

⁷² J. Geikie, "The Great Ice Age," 1895, pp. 290-293.

⁷³ S. B. J. Skertchly, "Fenland," pp. 140-143.

⁷⁴ C. B. Travis, "Geological Notes on Recent Dock Excavations at Liverpool and Birkenhead," *Proc. Liv. Geol. Soc.*, Vol. XI., 1913, pp. 237-275.

Sirodot⁷⁵ refers to a locality, where one finds a series of alternating peat and marine deposits, which he explains by supposing that a bar was formed and broken repeatedly, so that the enclosed area was alternately freshwater and marine.

But this burial comes also to inland deposits, to those on great deltas or at the heads of long estuaries, where the covering material is of freshwater origin. Much of the Holland-Belgium-France area, in all more than 7,000 square miles, was not under the sea at any time since the peat began to form; the great peat bed of the Ganges delta is at 20 to 50 feet below the somewhat irregular surface and is covered with river silts in an area of not less than 2,500 square miles. Entombment seems to be the fate of large and small alike. Phillips⁷⁶ has recorded the section of the Holderness peats, thus: (1) Clay; (2) peat, with plants, trees and roots; (3) variegated clays, with freshwater *Lymnaea*; (4) peat, like No. 2; (5) clay with freshwater Cyclads; (6) bituminous clay; (7) coarse sandy clay. Number 2 is the persistent member of the section, but varies greatly in thickness and character. Near Hull, it is 30 feet below the surface and 2 feet thick, containing large trees. Buried swamps abound on the Atlantic coast of the United States, especially along streams emptying into the long estuaries occupying "drowned valleys." One citation suffices to illustrate the conditions. Berry⁷⁷ says that such swamps are exposed by erosion at many places along the James, Rappahannock and Potomac Rivers, all emptying into Chesapeake bay. Most of those observed in 1907-09 were cypress swamps, though some were of the open type with birch, oak, pine and other forms. When quiet conditions accompanied subsidence of the forest bed, clay is the roof, containing *Unio*, if the locality be near the head of the estuary, or *Rangia cuneata*, if farther down within reach of saline water. This condition of quiet subsidence is shown in the photograph of an exposure

⁷⁵ Sirodot, "Age du gisement de Mont-Dol," etc., *Comptes Rendus*, Vol. 87, 1878, pp. 267-269.

⁷⁶ J. Phillips, "Illustrations of the Geology of Yorkshire," 2d ed., 1835, Vol. I., pp. 25-27.

⁷⁷ E. W. Berry, "Pleistocene Swamp Deposits in Virginia," *Amer. Naturalist*, Vol. XLIII., 1909, pp. 432-436.

near Tappahannock, Virginia, where a bed of massive hard peat is exposed for half a mile. This is covered with plastic clay, 1 to 4 feet, underlying 10 to 15 feet of coarse sand. One sees many cypress stumps in place, with their "knees" projecting into the sand. Where the subsidence was accompanied or followed by disturbance, the evidence appears in the more or less planed or eroded surface on which gravel or sands rest, as is shown in a photograph of peat with embedded cypress stumps, which is unconformable by erosion to the overlying sands.

Greater interest attaches to the interglacial buried peats, which have been covered with material transported during the Ice Age. These, underlying clays, sands or gravels, exhibit many features which are important here. Such deposits have been observed in many lands.

The deeply buried peat of Montgomery county, Ohio, originally studied by E. Orton, Sr., has been restudied by Dachnowski.⁷⁸ The exposure is in the bank of a tributary to the Miami River and underlies 80 to 100 feet of stratified clay and gravel. There are indications that the deposit is part of a large area and that it marks the deeper portion of an extensive water-basin. The thickness, as now exposed, is from 1 to 4 feet, but, 45 years ago when Orton's description was written, it was from 12 to 20 feet. The uppermost layers contain undecomposed sphagnum-mosses and underlie fine silty blue clay. The lower portions grade into a well-decomposed, very compact peat which holds fragments of wood. This peat rests on several feet of fine sand underlain by clay and gravel. Near the southern margin, according to Orton, a large quantity of timber was found, roots, branches and twigs, much of which had been flattened by pressure. The wood is largely but not exclusively coniferous. Newberry⁷⁹ recalled Collett's discovery in much of southern Indiana of a buried deposit, 2 to 20 feet thick, containing rooted stumps. In later years, W J McGee, F. Leverett, F. B. Taylor and J. W. Goldthwait have described interglacial deposits, some of which are very extensive.

⁷⁸ A. Dachnowski, "Peat Deposits of Ohio," Geol. Surv. Ohio, Bull. 16, 1912, pp. 102, 103.

⁷⁹ J. S. Newberry, "Geological Survey of Ohio," Vol. II., 1874, pp. 30-32.

Dunlop⁸⁰ has given details of a section observed by him at about two miles from Airdrie, Scotland. The order, descending, is (1) Alluvium, 3 feet; (2) peat, with trees standing up through it, 2 feet; (3) Upper Boulder clay, containing a 4-inch layer of vivianite near the bottom, 4 feet; (4) sand with partings of fine clay, 11 inches; (5) peat, 1 foot 5 inches; (6) Boulder clay, not measured. The upper peat bed is recent, but the lower is interglacial. The peat of the latter splits readily into layers and darkens somewhat rapidly on exposure. Some layers consist of seeds of *Hippuris vulgaris* and *Menyanthus trifoliata*; others are wholly of mosses and, near the bottom, are some containing abundant remains of beetles. But no traces were found of the trees usually found in bogs, aside from some leaves resembling willow. The cover is sand but silica is practically wanting in the peat, which, air-dried, contains 6 per cent. of ash, mostly oxide of iron. In this bed are boulders of sandstone and gneiss, varying in size and distributed irregularly; all are waterworn and those which are little disintegrated show ice-markings.

Reid's⁸¹ report, on behalf of a committee, which studied the deposits at Hoxne, on the border of Norfolk and Suffolk, England, relates that at that place a bed of lignite, 1 to 3 feet thick and disappearing at the borders of the valley, rests on a carbonaceous clay containing lacustrine shells and some drifted seeds. The bulk of the lignite consists of alder wood preserving the bark, offal from alders along with remains of other plants, all of the swamp-loving type—altogether, 37 species of flowering plants and 11 of mosses. The presence of pools in the swamp is indicated by the occurrence of *Vaivata*, *Pisidium*, rare fishbones and elytra of beetles in the lignite; every plant indicates a temperate climate. A black loam, 13 feet thick, overlies the lignite: it is beautifully laminated and contains well-preserved remains of plants belonging to a cold climate, the arctic willow and birch. Fragments of plants belonging to a temperate climate occur in this loam, but their condition shows that they were derived from the underlying deposit. Above the loam are

⁸⁰ R. Dunlop, "Note on a Section of Boulder-Clay, containing a Bed of Peat," *Trans. Geol. Soc. Glasgow*, Vol. VIII., pp. 312-324.

⁸¹ C. Reid, "The Relation of Paleolithic Man to the Glacial Epoch," *Rep. Brit. Assoc. Adv. Sci.*, 1896, pp. 400-415.

gravels and brick-clay, the latter containing freshwater shells, fragments of wood and paleolithic implements. These facts presented by Reid show that the peat has been converted by pressure into a lignite-like substance; the growth of the swamp was checked and the peat may have been exposed during the considerable period of changing climate, which led to the introduction of a subarctic flora. Direct superposition and conformability are certainly not evidence of continuity of deposition.

De la Harpe⁸² saw a bed of peat at Lausanne, Switzerland, one meter and a half thick, lying on gravel and resting on marl. The peat is mixed with gravel in its lowest part and the highest part contains some fine micaceous sand. Here and there in the black peat are occasional rock fragments, wholly isolated, as though one had cast them into the soft mass. Seeds, tree stems and branches, altogether decayed, were observed with, here and there in the upper part, a fragment of bark resembling birch. The underlying marl is without pebbles but has abundance of *Lymnaea*, *Valvata*, *Planorbis*, *Cyclas* and *Pisidium*.

Keilhack⁸³ saw a coal deposit near Lauenberg on the Elbe, with these relations, descending: (1) Upper clay, with shells; (2) diluvial sand, 15 meters; (3) coal bed, consisting of (a) fragmentary coal with stems and branches, (b) fruits and leaves, (c) moss; (4) clay; (5) diluvial sand with *Cardium edule*.

No additional details are given in the abstract. During the discussion, Hauchecorne and Beyrich insisted that the material is not coal but peat. Evidently the change in physical character was sufficient to make the relations somewhat doubtful. It is to be noted that the transformation is most advanced in the upper part and that the moss at the bottom appears to have undergone little change.

The deposits at Klinge, near Kottbus in Brandenburg, have given rise to much discussion as did that at Lauenberg. Keilhack⁸⁴ examined the great excavation and observed this succession, descend-

⁸² Ph. De la Harpe, "Sur un gisement de tourbe glaciaire," *Bull. Soc. Vaud. Lausanne*, Vol. XIV., 1877, pp. 456-458.

⁸³ Keilhack, *Zeitsch. d. d. geol. Gesell.*, Bd. XXXVII., 1885, p. 549.

⁸⁴ H. Keilhack, "Der Alter der Torflager und ihrer Begleitschichten von Klinge bei Kottbus," *Zeitsch. d. d. geol. Gesell.*, Bd. XLIV., 1892, pp. 369-371.

ing: (1) Diluvial sand, 2 to 2.5 meters; (2) carbonaceous clay, 1.2 meter; (3) brown coal, peat-like, 1 meter to 3 decimeters; (4) clay marl, 3 to 3.5 meters; (5) peat, 45 centimeters; the upper part is Moostorf with seeds and reeds, while the lower portion has leaves, wood, seeds, rhizomes of *Nymphaea*; (6) Lebertorf with diatoms, 1.1 meter.

The Lebertorf is a lens-like deposit and is replaced in the southern part of the excavation by a meter of sand. Keilhack could not determine the age of the beds and maintained that the matter could be determined only by a boring. A. Nehring, in the discussion, held that the deposit is interglacial and probably equivalent in age to the Schieferkohle of Utznach and Dürnten. Credner⁸⁵ visited the same locality and obtained a section, evidently from another portion of the excavation. The peat is a single bed with maximum of a meter and a half, Number 4 of Keilhack's section being absent. The Lebertorf rests on clayey marl overlying sand. He thinks that the peat is post-glacial. In the following year, Potonié⁸⁶ summed up conclusions presented by H. Credner, H. Keilhack, A. Nehring as well as by other observers and discussed in detail the relations of the flora found in the Klinge deposits. This is distinctly diluvial. The succession is that of so many peat-filled basins, Lebertorf below, succeeded by peat in which are many erect rooted stumps, clearly *in situ*. The compression, due to weight of the overlying deposit, had so changed the appearance that Keilhack thought it brown coal with peat-like features, while Credner preferred to call it peat with resemblance to brown coal.

Weber⁸⁷ described two interglacial peat deposits, exposed during excavation of a canal from the Elbe to the Eider. One, seen where the canal emerges upon the Eider lowland, is exposed for more than 1,600 feet. The underlying material varies. The bed is in two divisions separated by sand; the upper one has suffered much from disturbance and is broken up badly, while the lower one is practically

⁸⁵ H. Credner, "Ueber die geologische Stellung der Klinger Schichten," *Ber. Ges. Wiss. Leipzig*, Bd. XLIV., 1892, pp. 385-402.

⁸⁶ H. Potonié, *Naturwiss.-Wochenschrift.*, Bd. VIII., 1893, pp. 393 ff.

⁸⁷ C. Weber, "Ueber zwei Torflager im Bette des Nord-Ostsee-Canales bei Grüenthal," *Neues Jahrbuch*, 1891, Bd. III., pp. 62 ff.

undisturbed, though at one end of the exposure it is curved upward so as almost to reach the surface. The succession in the lower division is clearly that observed in peat-filled ponds. The quartz sand on which the peat rests is without lime; by increase of humic matter, it passes gradually into peat with roots, leaves and fruits of *Potamogeton* and rhizomes of *Phragmites*; *Hypnum fluitans* appears at the top of this bottom layer, which passes upward into a thin layer of hard peat, mostly *Hypnum fluitans* accompanied by *Potamogeton* and *Phragmites*, the latter increasing above. Indeterminate fragments of beetle-elytra, pollen of conifers and *Betula*, with spores of *Hypnum* are abundant. This in turn passes very gradually into the third layer, 65 centimeters thick, very sandy brittle peat, containing abundance of twigs and roots of *Pinus sylvestris* with leaves, seeds and wood of *Betula verrucosa*, leaves of willow and wood of *Corylus*; there is much compressed wood, probably willow, some wood of fir and juniper was seen along with rhizomes of *Nuphar*, *Typha*, *Potamogeton*, etc. The highest layer is moss-peat, about a meter and a half thick, mostly *Hypnum hamifolius* with very little wood and rare *Sphagnum*.

The conditions are similar to those recorded in many recent peat deposits. But during deposition of the overlying sand, as shown by Weber's profile, the lower beds suffered much from erosion at one side, where the upper surface is jagged. The whole mass, including both divisions and the sand parting, has been subjected to severe lateral pressure, producing disruption of the upper division, upturning of both, so that the old peat deposit is almost united to the recent bog covering the present surface.

Molengraaff⁸⁸ reports that, in Borneo on the Mandai river, he saw thin layers of peat alternating with clay loam, the peat so compressed as to resemble brown coal. On the same river he saw thin beds of coal, evidently of recent origin; it is of poor quality, is laminated, lustrous, and has cleavage in two directions, breaking into parallelopipedons.

The deposits of Schieferkohle show similar features but on a much more extensive scale. Heer⁸⁹ examined the Schieferkohle at

⁸⁸ G. A. F. Molengraaff, "Borneo," etc., Eng. ed., p. 43.

⁸⁹ O. Heer, "Die Schieferkohle von Utznach und Dürnten," Zurich, 1858,

Dürnten, where he found about 12 feet of coal resting on marly clay, with freshwater mollusks, and underlying about 30 feet of sand and gravel. The bed is divided by six partings of dark earthy material unfit for fuel and, in all, about 2 feet thick. The benches of coal are not alike. The lowest contains much wood and cones of *Pinus abies*, which are wanting in higher parts of the bed. In each of the upper benches, one finds, first, layers of moss felted into dense masses and pierced by reeds, which are followed by trunks lying in all directions, associated with roots, barks and pieces of wood, seldom very thick and always pressed flat. The annual rings are distinct though, at times, they have been distorted by the pressure. Some stems are wholly coaled as if by lightning. The tree trunks, as in peat, are embedded in a brown-black substance, derived unquestionably from herbaceous plants and originally forming a pulpy mass. This succession appears in every bench except the highest, in which reeds and mosses predominate, while stems of trees are comparatively rare. At Unterwetzikon, the lignite rests on marl with freshwater shells. At Utnach, there are two beds of lignite, 5 and 3 feet thick, separated by 16 to 20 feet of marly deposits. At Morschwyl, the Schieferkohle, variable in thickness, overlies and underlies marl and has a cover of 26 to 70 feet. It contains vertical stems, which in many cases extend into the overlying marl.

Heer's study of the plants proved that the resemblance of Schieferkohle to peat is complete. The trees are *Pinus abies*, *P. sylvestris* and *P. montana*, which are prostrate—they must have been overturned and been sunken in the bog. The wood is soft when first removed, but it hardens quickly on exposure; the bark is commonly present and twigs and branches, retaining the leaves, occur frequently. Other trees are yew, larch, white birch and sycamore. The last is represented by a few leaves in the lignitiferous clays. *Corylus* is not rare; *Menyanthus* is represented by abundant seeds and *Phragmites* abounds in the clay partings with *Scirpus*; *Sphagnum* and three species of *Hypnum* were obtained at Dürnten. The Schieferkohle and its partings contain abundance of mussels and swamp in-

pp. 7-11; "The Primæval World of Switzerland," London, 1876, Vol. I., pp. 29, 30; Vol. II., 155, 157, 160-163.

sects, while among the higher animals which perished in the bog are *Rhinoceros leptorhinus* and *Elephas antiquus*.

Deicke⁹⁰ looks upon the Swiss diluvial coal as a link between peat and brown coal; it passes over into both types. He discussed only the Morschwyl deposit as Heer had given details respecting those at Utnach and Dürnten. The coal lies in diluvium, 40 to 50 feet above the Miocene, is covered with drift-material, often 80 feet thick, and rests on ashen-gray shale or on a clayey sand containing small pebbles. The lowest coal layer encloses very many stems of trees, among which Scotch fir, red and white spruces, oaks, birches and others can be identified. All had been broken off and the fragments are from 8 to 12 feet long with, in some cases, a diameter of 3 feet. Except where the stumps are rooted, the stems are prostrate and show very marked compression. Birches are much flattened, the width of a stem being often 24 times its thickness. Conifers are less compressed, the width being rarely more than 4 times the thickness. Above this layer is a clay-shale parting, one foot thick, on which rests a coal composed chiefly of grasses and mosses, but containing many birches, some Scotch firs and rare spruces. In the clay shale and in the lower coal, Deicke found a great quantity of cones of Scotch fir, red and white spruce, rare cupules of oak, seeds of various grasses and wings of insects. The second bench of coal is succeeded by 4 feet of coaly shale, on which is another coal bed, averaging 3 feet and broken by shaly partings. The whole deposit thins away toward the borders. The coaly shale has nests of Schieferkohle and shows erect stems which, though fractured, are not compressed. Deicke recognizes Waldmoor conditions here; a forest was overwhelmed by mud, on which a Torfmoor developed. The trees died and were blown over; cones of spruce and fir remained in the mud and projected into the growing peat; Scotch firs, birches and the rest grew on the peat and were destroyed, when that material increased. Then came the influx of detritus and the resulting compression. Wood comprises about one tenth of the mass. When exposed to the air and sunshine, the lignite changes, loses texture and becomes Pechkohle; but complete change takes

⁹⁰ J. C. Deicke, "Ueber die Diluvial-Kohle bei Morschwyl im Kanton St. Gallen," *Neues Jahrbuch*, 1858, pp. 659-663.

place only in small stems and is rare when the diameter exceeds 2 inches. One end of a stem may be changed while the other retains its woody structure.

Klebs⁹¹ described a coal which he saw at about 30 miles southwest from Königsberg: it underlies 15 feet of sand and overlies gravel, both of them diluvial. The section, descending, is: Black earthy coal, 1 foot; clear brown coal, 7 inches; dark, brown coal, 3 inches. The three benches are as sharply distinct as those of any peat bog or bed of stone coal. The whole thickness, including the thin partings, is 2 feet and the middle bench is harder than that above it.

Von Gümbel,⁹² who had studied the Bavarian Schieferkohle in place, subjected to microscopical examination material collected at localities in Bavaria and Switzerland. He describes the Schieferkohle as partly loose, partly dense in structure, often like Pechkohle. It contains many flattened branches and parts of trees belonging to conifers, birch, willow, alder, in part lignite but at times already Pechkohle. Solution of caustic potash converts the less dense portion into a soft closely felted mass, in which the microscope shows, as predominating, parts of mosses and grass leaves. Tissue of wood appears rarely. The dense Pechkohle required treatment with Bleichflüssigkeit (potassium chlorate and nitric acid) in order to bring out the structure. The densest material is that from Morschwyl, which shows the same plants as those in the looser or less dense portions along with an amorphous textureless substance like dopplerite. The density is due to this material, which he terms Carbohumen. Pollen, spores of mosses and lichens are not very abundant; cones of conifers are numerous in the coal mass, but are little deformed though they lie alongside of compressed stems. The inside of stems is yellowish and soft like decayed wood, but the bark zone has been converted into bright Pechkohle.

The Bavarian localities are typical. At Imbergtobal, near Sonthofen, a brown coal deposit is divided by partings of sandy marl, which are crowded with plant fragments and conifer needles.

⁹¹ R. Klebs, "Die Braunkohlenformation um Heiligenbeil," *Schrift. Ges. Königsberg*, Jahrg. 21, 1880, p. 82.

⁹² C. W. v. Gümbel, "Beiträge," etc., pp. 135-138.

and have the features suggesting deposition by floods, which repeatedly overspread the continuously growing peat. They bear close resemblance to the partings seen in most coal beds. At Grossweil, near the Kochelsee, the Schieferkohle consists of easily separated layers of brown coal, twigs and wood fragments with others of leaves of grasses and mosses. The composition is made clear by solution of caustic potash. *Sphagnum* is the chief constituent of the moss layers; in others, pollen is abundant with small nests of fibrous peat and an alga. The deposit is distinctly one of peat and, at all localities, the coal-like and the peat-like portions pass gradually into each other.

Von Ammon⁹³ has given some notes respecting the distribution of Bavarian Schieferkohle. He states that a diluvial formation extends along the Loisach in an area of 9 by 2 kilometers between the Murnauer Moos and the Kochelsee. In this is embedded the coal bed mined near Grossweil (about 40 miles south-southwest from München), which he thinks is a forested Flachmoor of intramorainal age. It was opened at one time near Ohlstadt, where it is double and about 1.6 meter thick. At 10 meters above is another bed showing coal, 0.7 and 0.6 meter, separated by a parting of one meter. The coal is an earthy brown coal with inclusion of lignite. The Schieferkohle of Sonthofen varies much but is often several feet thick. At Josephsfelde, the thickness is from one to 3 meters; at Imbergtobal, there are two beds, three meters apart; the lower is from 2 to 5 meters thick and upper about 1.5 meter and impure.

Schieferkohle occurs in extensive deposits within Upper Austria, Styria and Tyrol. Lorenz⁹⁴ reported upon the conditions observed by him in the Hausrucker mountains of Upper Austria. The succession is: Fragmentary material, Kohle-Tegel system, Tegel, and the deposits appear to be conformable. The coal-marl system is from 100 to 150 feet thick and at most localities it shows three coal beds. The top and bottom beds are 7 to 8 feet thick, but the middle one is 12 feet. The lower beds are separated by a small

⁹³ L. v. Ammon, "Bayerische Braunkohlen und ihre Verwertung," München, 1911, pp. 9, 10, 63.

⁹⁴ J. R. Lorenz, "Ueber die Entstehung der Hausrucker Kohlenlager," Sitz.-Ber. k. Akad. Wiss. Wien, Bd. XXII., 1857, pp. 660-664.

interval, but the top bed is usually about 90 feet above the second. Each bed is limited above and below by coaly shale, 2 inches to 2 feet thick, which passes gradually into gray-blue marly clay. The lower beds are double, divided by carbonaceous shale. The parting in the lower bed is 2 inches thick, at 2 to 3 feet from the floor and is known as the "Hohl-lag"; that in the middle bed, known as the "Koth-lag," is almost paper-thin but is persistent. Besides these there occur occasionally in these beds layers of charred material, one third to one half inch thick and termed "Brand-lag"; they are of limited extent and cannot be regarded as partings. As the peculiarities of the beds convinced the author that these are composed of *in situ* plants, he explains the "Brand-lag" as derived from burned vegetable matter—that possibly the surface of the deposit had been ignited by lightning. After the fire had burned out, vegetation began anew. The mass of charred matter is enclosed in unchanged lignite, the separation being sharply defined.

Schreiber⁹⁵ has referred to two diluvial moors, one near Piehl in Styria and the other at Hopfgarten in Tyrol. That at Piehl is at 200 meters above the bottom of the present valley and is from one to one and a half meter thick. It underlies 150 meters of conglomeratic materials, and this great burden has so compressed it that it resembles brown coal; but Schreiber objects strenuously to the term Schieferkohle, preferring Schiefertorf, to distinguish it more sharply from the Tertiary brown coal. At Piehl, it rests on a marl; the lowest layer is brown hypnetum peat with loose texture, on which rests reed or rush peat, containing much earthy matter. Then follows a comparatively thick layer of Bruchtorf, composed chiefly of firs and birches. The highest layer is a sedge-moss peat and is thin at all localities examined by Schreiber. Overlying this bed is sandy clay, succeeded by moraine stuff and glacial débris. The Hopfgarten deposit overlies more than 100 meters of glacial débris, from which it is separated by clay bands. It was measured at three places and the thickness seems to be almost constant at about a meter and a half. The lowest portion is Riedtorf, with much mud and consisting mostly of sedges, though, here and there,

⁹⁵ H. Schreiber, "Vergletscherung und Moorbildung," etc., pp. 27-29.

reed and brown moss peat are shown. Well-marked Bruchtorf follows, composed mostly of Fichte, though occasional specimens of Scotch fir and birch were seen. According to Zailier, the sedge-moss peat follows, but Schreiber saw only a mere fragment of it. The deposit underlies moraine stuff. The Hopfgarten peat is less like coal than that at Piehl, though both are of the same age. Schreiber explains this by difference in the pressure.

Bursting Bogs.—Peat often remains a long time in the condition of "quaking bog." The floating mat constantly increases in thickness, so that at length it can carry large trees; but, under it, material from the bottom of the mat accumulates slowly and is pulpy. After long-continued rains, water may collect in such quantity as to break the cover and the black mud may be discharged upon lower levels. Lyell,⁹⁶ referring to the Solway moss in southern Scotland, states that its surface, covered with grass and rushes, shakes under the least pressure, the bottom being unsound and semi-fluid. On December 16, 1772, having been filled like a sponge during long-continued heavy rains, this bog swelled above the surrounding area and finally burst. A stream of half consolidated black mud crept over the plain with speed like that of an ordinary lava-current. The deluge covered about 400 acres. Tait⁹⁷ says that a very great part of the moss of Kincardine is a quaking bog, the peat being so wet as to be semi-fluid. During the process of reclamation, the support for the mass was removed and, on March 21, 1792, the peat began to run on the west side and the flow covered about an acre. On the same day in 1793, the flow was repeated and the peat mud covered nearly 12 acres of the cleared space. The extreme depth of the overflow was 8 feet.

The phenomenon is by no means rare. Lyell conceives that lakes and arms of the sea must occasionally become receptacles of drift peat; and in this way he would explain alternations of clay and sand with deposits of peat, found frequently on some coasts. This explanation would suffice only for some indefinite and insignificant deposits; it is difficult to conceive how the required con-

⁹⁶ C. Lyell, "Principles of Geology," New York, 1872, Vol. II., pp. 510, 511.

⁹⁷ C. Tait, "An Account of the Peat-Mosses of Kincardine and Flanders, Perthshire," *Trans. Roy. Soc. Edinburgh*, Vol. III., 1794, p. 278.

ditions could exist on great plains; lake deposits are too small to be important in this connection.

The Floor or Mur of Peat Deposits.—In regions where calcareous matter abounds, the floor of peat originating in ponds or lakes is apt to be the familiar lake marl, formed by *Chara* and mollusks, and containing other freshwater forms. Where calcareous matter is lacking, fine clay is the usual floor. Marl and clay are almost impervious; the impression has prevailed that peat grows only on a floor impervious to water.

But marshes and bog deposits may originate on rock of any sort, which is free from constituents injurious to plant life. The great Okefinokee Swamp of Georgia and the much greater Dismal Swamp of Virginia and North Carolina rest, in great part, on sand and in each the peat is thick. The buried peat of the Holland-Belgium-France area has mostly a floor of blue clay, though in many places it rests on sand. Typical freshwater peat may overlie marine sands, clays or limestones. The Carse land peats of Scotland, according to J. Geikie, have as the floor marine sands or marine clays; Moggridge found a similar condition in the Swansea excavations. Rohhumus or Trockentorf, so familiar in our forests, grows on bare rock; even granite may be the floor.

Davis⁹⁸ saw "climbing bogs" in northern Michigan, which had grown on smooth glacier polished granite. One, on an isolated rock hill, showed *Sphagnum* in spots, evidently thrifty and making a good growth, but most of the surface was covered with reindeer lichen, both in the open and under trees and shrubs. The peaty cover is thin and fibrous, with little moisture, but this supports the usual trees and shrubs, conifers with white birch and mountain ash as well as some heaths. A small island, with rounded glaciated surface and embracing about 3 acres, rises about 30 feet above Bubbling lake. The peat covering it is usually thin, about one foot but occasionally reaching 3 feet. It is coarse, spongy and brown, contains tree trunks, not thoroughly rotted, along with abundant partially decayed roots and stems of plants. When this locality was examined, the peat was so dry as to burn. The flora consists of the conifer-

⁹⁸ C. A. Davis, "Peat," 1907, pp. 264-269.

heath society. An indication of the mode in which peat formation began was observed on the north side of this island, where some spaces of otherwise bare rock were covered with a mat of *Sphagnum* with other mosses and lichens. As soon as these form their deposit, other plants obtain foothold and thenceforward accumulation of peat is continuous, if atmospheric conditions remain favorable. The growth of peat in a region where rain, at times, is wanting for weeks and where the soil is a coarse peat, only an inch or two deep and resting on a smooth rock, is due to condensation of atmospheric moisture in fogs. The plant society of this high, dry peat bed is very closely allied to that which characterizes the older and more mature portions of peat beds with a rock substratum—a confirmation of the belief that both are xerophytic habitats.

Chevalier's⁹⁹ observations in the Niger area, between 5° and 9° N.L., show that in that region, at 200 to 400 meters above sea-level, a sedge grows luxuriantly on the bare granite and gneiss, where it attaches itself so firmly as to resist the winds and the tropical rains. There, in hundreds of square miles within French West Africa, this sedge-growth has caused an accumulation of peat, 5 to 30 centimeters thick. The conditions are wholly unfavorable to increase of peat, as there is a dry season, during which the plants wither and the loss is accentuated by fires; yet the surface is covered with a fibrous material, described as very humic.

Ordinarily, however, some organic film is necessary, if the growth is to be rapid. As already stated, those engaged in the peat industry learned long ago that, if peat be removed wholly so as to lay bare the underclay, regeneration of the bog is very slow; but if a thin cover of peat be left on the floor, it is more rapid. The passage from the floor to clean peat may be gradual or abrupt. If the accumulation be in a pond, the transition may be marked by a faux-mur, showing laminæ of sand, clay or marl and peat, or it may consist more or less of the Lebertorf or Sapropel mud. In other types of deposits this faux-mur may consist of alternating peat and silt or sand, evidence of repeated flooding before the peat-forming plants gained the mastery. At times the passage is abrupt,

⁹⁹ A. Chevalier, "Les tourbières de rocher de l'Afrique tropicale," *Comptes Rendus*, Vol. 149, 1909, pp. 134-136.

especially where expansion of the bog was by transgression, as is so often observed in plain deposits. The peat itself may be the mur for a new deposit, as where the drying of the upper portion invites invasion by a forest growth, to be destroyed by increasing moisture and return of bog conditions.

A very notable feature of the mur is the abundance at many places of roots and rooted stumps. This has been observed in all parts of the world, and the instances are so numerous that only a few need be cited as illustrations. Tait¹⁰⁰ states that the mosses described by him cover about 9,000 acres. The lowest part of the peat consists very largely of decayed wood, mingled with some black earth and occasional bunches of heather, better developed than those now growing on the surface of the bog. Innumerable tree trunks are at the bottom, lying alongside of their stumps, which, like the heath bundles, are still fixed in the clay. A considerable portion of the moss has been reclaimed by drainage and by complete removal of the peat. The trees at the bottom are oak, birch, hazel, alder, willow and, in one place, a few firs. In one clearing, 40 large oak trunks were found lying by their rooted stumps. These stumps, rooted in the clay, rise about 3 feet and are so little changed that they can be removed only with difficulty. But the stumps of other trees are so badly decayed that little can be said about them except that they are rooted in the underclay. Aiton¹⁰¹ has remarked that the suggestion that peat deposits originated in forests is abundantly supported by the very frequent occurrence of trees or roots in the underclay. He never had examined a moss of any great extent without finding on its borders and where the peat had been removed "roots of trees still in the ground with their fangs extended as they grew." Along the river Aven, roots of trees are found under every moss "with their shoots firmly clasped into the earth, where they grew." Geikie¹⁰² says that in many mosses, the tree stumps are of approximately uniform height and that the

¹⁰⁰ C. Tait, "Peat-Mosses of Kincardine," etc., pp. 228, 269, 271, 272.

¹⁰¹ W. Aiton, "A Treatise on the Origin, Qualities and Cultivation of Moss-Earth," Glasgow, 1805, pp. 29, 33.

¹⁰² J. Geikie, "On the Buried Forests and Peat-Mosses of Scotland," *Trans. Roy. Soc. Edinb.*, Vol. XXIV., 1867, pp. 379, 381.

peat grows over the trees which it has killed. A moss on the Isle of Man shows large trees, erect in place, with 20 feet of peat over them.

In 1837, the officers of the Ordnance Survey¹⁰³ reported that the lowest layer of fir trees overlies 3 to 5 feet of turf; but not so with the oaks, as their stumps are commonly found resting on the gravel or on small hillocks of gravel and sand, which so often stud the surfaces of bogs.

Reade¹⁰⁴ has shown that a railway cutting through Glazebrook moss exposed 18 feet of peat containing, in a thickness of 3 to 4 feet near the base, remains of trees and branches embedded in the peat. When the peat has been removed, one sees the oak and birch stools rooted in the underclay. A fine overturned tree with roots attached was exposed. It was 46 feet long and 3 feet in diameter just above the root.

Skertchly's¹⁰⁵ observations are equally to the point. In describing conditions in the Fenland counties of England, he says that trees are to be found in the peat everywhere, but that Digby and Bourn for the north and near Ely for the south are the most convenient localities for study. At these places, the trees rooted *in situ* are mostly oaks and are often of gigantic size; in not a few instances, the stems are 70 to 80 feet long and clear to the branch, distinct evidence of forest growth. In one moor he examined an overturned tree, which was 36 feet long with maximum diameter of 30 inches. Bark was preserved on the underside of the tree, but was carbonized and it crumbled into cuboidal fragments. In another fen, oaks are numerous and all are broken off at 2 to 3 feet from the ground, that is at the top of the peat. Some birches were here but only the bark remains; a few elms also, which were

¹⁰³ "Ordnance Survey and Report of the County of Londonderry," cited by R. C. Taylor, "Statistics of Coal," 2d ed., 1855, p. 169.

"It is a very remarkable fact, though very common, that successive layers of stumps and trees, in the erect position and furnished with all their roots, are found at distinctly different levels and at a small vertical distance from each other."

¹⁰⁴ T. M. Reade, "On a Section through Glazebrook Moss, Lancashire," *Quart. Journ. Geol. Soc.*, Vol. 34, 1878, pp. 808, 810.

¹⁰⁵ S. B. J. Skertchly, "Geology of the Fenland," pp. 158-162, 167.

recognized by their bark, the wood having decayed. Near Ely, he found a forest of yews, which penetrated the underclay into a thin layer of sand, in which their roots were spread out horizontally; thence the stems passed upward into the peat. In another fen, where the lowest peat is fetid and is known as "bears' muck," he saw a forest of oaks with roots extending into the Kimmeridge Clay below. The stumps, broken off usually at 3 feet from the roots, are associated with the prostrate stems.

Lorié¹⁰⁶ cites Belpaire père to the effect that in Zeeland trees rooted in the subsoil occur frequently in the peat. In discussing the conditions within an area of 1,400 square miles in Holland, Lorié says one finds there one or more peat beds covered with a greater or less thickness of sediment; these are autochthonous and contain stems of trees rooted in the subsoil. He has described a fossil forest near Fochtelos in the great Hochmoor of Smilde, Holland. Formerly, one saw there only a marshy heath; but the surface was lowered by drainage and by cultivation of buckwheat, so that the forest became visible. The trees are oaks with some aspens. The greater proportion of them have been broken off near the surface, probably after death, and the stems lie usually in a southwest to northeast direction. Those examined by Lorié appeared to be rooted in the peat but very near the bottom; but his guide maintained that all the fully exposed stumps seen by him were rooted in the subsoil.

Sections published in works on the Scandinavian swamps show the frequency of trees in the lower part of peat deposits, rooted in the underclay. Von Post¹⁰⁷ has published a photograph of the forest bed in the Tarnsjomoor, which had been exposed by removal of the peat.

Potonié¹⁰⁸ has discussed a great moor near Stelle, which is accessible in dry years. At one locality he saw, underlying 0.03 meter of sedge-peat, on which is one meter of sphagnum-peat, a forest

¹⁰⁶ J. Lorié, *Arch. Mus. Teyler*, II., Vol. III., 1890, pp. 424-427; II., Vol. IV., 1893, p. 183.

¹⁰⁷ L. Von Post, "Die Torfmoore Narkes," *C. R. XII^{me} Cong. Geol. Int.*, Stockholm, 1912, pp. 1282, 1283.

¹⁰⁸ H. Potonié, "Ueber Autochthonie von Karbonkohlen-Flotzen," etc., *Jahrb. d. k. preuss. geol. Landesanst.*, 1895, pp. 25, 26: "Die Entstehung der Steinkohle," *Naturw.-Wochenschr.*, II., Bd. IV., 1905, pp. 7-9.

bed, which is filled with many large and small remains of firs, yews, oaks, birches and alders. The stems are mostly prostrate but with them are many stumps of fir and oak rooted in the bed. The same author, in a later publication, asserts that a Hochmoor may originate on a bed of sand if only there be sufficient moisture. To prove his position, he gives a reproduction of a photograph showing the floor of an extensive Hochmoor, which expanded by encroachment upon a forest growing on sand. The vertical stumps are exposed where the peat was removed.

The condition is familiar in the United States; G. H. Cook, N. S. Shaler, C. A. Davis, D. W. Johnson and others have considered the subject in detail. Davis has described conditions in the Pocosons or swamps on the coastal plain in North Carolina. But there are many peat deposits which did not originate on forested areas; those have no trees rooted in the soil below. There are others beginning in open area but expanding by transgression into a forested area; these have the rooted trees in one portion but not in the other.

It is unnecessary to cite evidence that the peat itself may be a soil for growth of non-water-loving trees. In every land, the peat deposits show successive forest beds, the trees being rooted in the peat and not penetrating to the underclay or subsoil. Numerous instances have been noted in preceding pages. But it is well to emphasize the fact that the opinion that plants have repugnance to thrusting their roots down into peat and that trees do not grow on peat, living or dead, is wholly erroneous. Plants disliking an acid soil certainly do not thrive on peat; but there are plants for which an acid soil is essential. Among these are some of the largest trees of America. That they have grown luxuriantly is certain, for in many of the extensive peat deposits in this country, the peat is commercially worthless because it is so crowded with stumps and stems. In many vast swamps of the coastal plain, a sounding rod cannot be thrust to the bottom and a similar condition has been reported from many places in the interior.

The Roof or Toit.—The roof of a buried peat bog may be as variable as the floor. It may be sand, clay or marl, freshwater or marine; the transition may be gradual, a faux-toit consisting of

alternating laminae of peat and sediment; or it may be abrupt. Of course, the trees growing on the surface of the bog cannot escape when the bog is killed; if the floods be violent and the winds be high many of the trees, rooted in yielding soil, will be overturned; but if the covering material be conveyed by the ordinary winds or by an overflowing flood, the larger number of the trees will remain erect or at most inclined. Davis¹⁰⁹ has given an illustrative case. He has figured a standing tree trunk seen near Marquette, Michigan. The outer dune at that place had been cut by a storm only a few days before his visit. The waves had undercut the bank and the sand had slipped off, leaving a vertical face. Near the base was a layer of peat, one foot thick, filled with unchanged roots of shrubs and Norway pine. A partly decayed trunk of pine, rooted in the peat, its roots not extending below it, rises 8 feet through the overlying sand. That the accumulation resting on the peat was not due to a sudden overwhelming is clear, for at 2 feet above the peat is a layer of Norway pine needles, while from that to the surface, are irregular layers of sand with roots of trees, grasses and leaves of pine. The accumulation was slow enough to permit vegetable growth at several levels, but the stem did not break away, though the climate is moist. It is possible for trees to remain alive for a long time after a thick cover of porous material has been laid on the surface. Geinitz,¹¹⁰ has described a forest of great oaks and beeches, growing on a bed of peat and covered in part by a dune. On the surface of the advancing dune, one sees, as it were, thick-stemmed oak and beech shrubs; but these are merely the upper portions of trees, still living, but in great part buried in the loose sand. At Morschwyl in Switzerland, where the overlying deposit is fine-grained, stems 6 feet high project from the peat into the marl above. Berry has described the buried bog on the Chesapeake waters, where the cypress knees pass into the overlying deposit. Seventy years ago, Lesquereux found leaves in the marl overlying peat and the partings of Schieferkohle have plant impressions. These leaves are transported material.

At several localities to which reference has been made, one finds

¹⁰⁹ C. A. Davis, "Peat," 1907, p. 253.

¹¹⁰ F. E. Geinitz, "Nach der Sturmflut," *Aus der Natur*, Vol. IX., 1908, pp. 76-83.

a succession of peat beds, separated by clay, sand or marl, while peat is forming on the present surface. Some of these beds show trees rooted in the underlying material.

Soils of Vegetation.—The rocks intervening between peat horizons occasionally show what may be termed soils of vegetation, on which plants grew but no peat accumulated. Thomson¹¹¹ states that in making excavation for a naval dock in Bermuda, this succession was found, beginning at 25 feet below the surface: (1) Calcareous mud, 5 feet; (2) coral crust, 20 feet; (3) a kind of peat and vegetable soil, containing stumps of cedars in vertical position and the remnants of other land vegetation with remains of *Helix bermudensis* and of several birds.

This old soil of vegetation rests on the usual "base rock" of the islands. Buried soils of vegetation have been noticed by all students who have visited the Bermudas. They are distinct at several places along the south shore where, in 1895, the dead cedar forest with trunks still erect protruded through the æolian beds, which in many spots were already covered with a dense growth of oleander and young cedars. No peat is found in the Bermudas except in "sinkholes" and estuaries; the porous rock permits rainwater to pass down quickly to tide level so that neither spring nor stream exists on the islands; but one finds buried soils with *Helix* and plant remains at various levels in the "sandstone" as the slightly consolidated æolian rock is termed.

Hilgard¹¹² saw, near Port Hudson on the Mississippi, brown muck overlying white or blue clay and underlying 93 feet of later deposits. This muck, 3 to 4 feet thick, contains cypress stumps, representing three, perhaps four generations. The stumps are rooted in the tough, somewhat sandy underclay. A similar deposit was seen at many places within lower Louisiana and usually several generations of cypress trees are shown. At one locality, huge stumps, 5 to 8 feet high, have their roots buried in a stratum of brown clay; the tops of

¹¹¹ C. W. Thomson, "The Atlantic," 1878, Vol. I., pp. 297, 298.

¹¹² E. W. Hilgard, "On the Geology of Lower Louisiana and the Salt Deposit on Petite Anse Island," *Smithson. Contrib.*, No. 248, 1872, pp. 5, 6, 7, 9, 11, 26.

the stumps are surrounded by similar clay but the middle portion is enveloped in yellow silt. A reddish loam is the superincumbent material to the surface. At about a mile below the Port Hudson locality, a deposit was seen, 30 feet above the stump horizon and resembling a river sandbar both in structure and contents. There, one finds no stumps but abundance of large drifted stems belonging to several species and some of them erect. These last, as Hilgard describes them, can be no other than "snags," which are even now only too numerous on sandbars along the river's present channel. At many places one finds living cypress swamps on the newer deposits.

The deep oil wells of the delta, according to Harris,¹¹³ have proved that there are many muck beds in the Recent deposits of the delta region.

A section measured by Colenso¹¹⁴ in the tin-producing area of Cornwall shows features not unlike those observed by Hilgard near Port Hudson: the succession is (1) Bed of river sand and gravel, 20 feet; (2) sand, containing tree trunks lying in all directions and mostly oaks, with bones of various mammals, red deer and whales, 20 feet; (3) silt or clay, 2 feet; (4) sand with marine shells, contains salt, 4 inches; (5) sludge or silt, contains recent shells and bones of mammals, 10 feet; (6) dark silt mixed with decomposed organic matter, about 12 inches, on which is a layer of leaves, hazel nuts, sticks and moss, 6 to 12 inches, this mass is apparently in place of growth and extends with some interruptions across the valley; (7) tinground, thickness varying according to irregularities of the underlying rock surface. Roots of trees are seen in this "ground" and on top of it oyster shells still remain fastened to some of the larger stones and to stumps of trees. The roots of oaks are in their normal position and can be traced to their smallest fibers, even as deep as 2 feet.

Here one has the soil of vegetation with its trees while, above it, are layers containing drifted logs and others of distinctly marine origin. It is worth noting that, at Sandycrook in the same district,

¹¹³ G. D. Harris, *Geol. Surv. of Louisiana, Rep. for 1905*, pp. 233, 240.

¹¹⁴ J. W. Colenso, "Description of Happy-Union Tin Stream-work at Pentuan," *Trans. R. Geol. Soc. Cornwall*, Vol. IV., 1832, pp. 29-39.

Rashleigh¹¹⁵ found 4 feet of peat in the upper part of the section, while the merely vegetable soil of Colenso's section is "solid black fen."

The presence of trees unassociated with peat has been regarded by some as evidence of allochthonous origin, as reforestation of an area after entombment of the peat seemed improbable. But reforestation is comparatively rapid on a new surface, provided only that there be moisture. During the great Missouri River flood of 1903,¹¹⁶ the water, diverted from the channel by obstructions piled against a railroad bridge, swept over a wide area. Crops were ruined and a nursery field, near Topeka, Kansas, was covered with sand, which buried the young trees. But within three months, the naked fields were green with young cottonwoods, growing from seed blown in after subsidence of the flood waters. Even dunes, consisting of loose sand, become covered with vegetation and eventually with forest.

Reforestation is rapid even amid untoward conditions. Seventy-five years ago, the White Mountains of New Hampshire were covered with a dense forest, mostly spruce. Lumbermen denuded a very great part of the surface and their labors were supplemented by forest fires, which destroyed trees elsewhere. Where the soil was burned off, so as to be washed away and to expose the glaciated surface, nothing grew; but elsewhere the restoration was rapid. Plants of various types took prompt possession and prevented erosion. They were succeeded by birch and cherry, in whose shade the conifers grew. On the neglected farms of that region, one finds all stages of restoration, from pasture lots invaded by sturdy weeds to the forest of fir and spruces, which have overcome the birches. The conditions are similar in Ontario, as Miller and Knight¹¹⁷ have shown. Their statement respecting one area is:

"Years ago, the area was visited by heavy fires which destroyed all but a few of the pine trees that were numerous and made the area important for its timber. On the part of the lake referred to, a few red pines and one or

¹¹⁵ P. Rashleigh, "An Account of the Alluvial Depositions at Sandrycock," *Trans. R. Geol. Soc. Cornwall*, Vol. II., 1822, p. 282.

¹¹⁶ H. C. Frankenfield, "The Floods of the Spring of 1903 in the Mississippi Watershed," *Bull. M. U. S. Weather Bureau*, 1904, p. 62.

¹¹⁷ W. G. Miller and C. W. Knight, "Pre-Cambrian Geology of South-eastern Ontario," *Toronto*, 1914, p. 18.

two white ones escaped the fire and were left as seed trees. Poplars have since grown up and now have a height of fifty or sixty feet or more. Back from the shore, where the seed has been blown, in the shade of the poplars, there is now a pretty growth of young pine trees, four or five feet in height."

In a letter, W. G. Miller states that the condition is familiar in many portions of Ontario.

Rock streams may still be seen at many places in the Allegheny mountains and in their path the forest has been removed. But even these coarse breccias become covered. Agnew¹¹⁸ says that, when he returned by canal from Harrisburg to western Pennsylvania, he observed long stretches of stone-covered mountain side, bare of all vegetation from base to summit, the slope varying from 25 to 40 degrees. In later years, coming to Harrisburg to sit on the Supreme bench, he could find none of the naked spaces. The rocky surface had become covered with trees, the few remaining bare spaces being merely dots in the forest. The writer may add his testimony to the same effect. Rock streams are not wanting now in the Allegheny Mountains but they are not those, which were striking features in the scenery forty years ago; they are of later origin.

Forest growth may appear quickly after an area has emerged from marine conditions. One finds dense forests and great peat deposits directly on Post-Pliocene marine beds at many places along the Atlantic coastal plain of the United States. Darwin¹¹⁹ saw on the island of Chiloe a bed of marine shells, the species being *Venus costellata* and *Ostrea edulis*, both now living in the adjacent bays. These were closely packed, embedded in and covered by a very black, damp, peaty mould, 2 to 3 feet thick, out of which a great forest of trees was growing.

It has been shown that forests on plains or even on rolling surfaces may bring about formation of peat deposits, but this does not occur always. Trees growing on peat have been entombed, others not associated with peat have met similar fate. River deposits have overspread extensive areas of forest, so that one finds in the rock

¹¹⁸ D. Agnew, "Nature's Reforesting," *Proc. Amer. Phil. Soc.*, Vol. XVIII., 1878, pp. 26, 27.

¹¹⁹ C. Darwin, "Geological Observations in South America," London, 1846, p. 28.

separating peat beds, trees singly or grouped, growing from an ancient soil with but small accumulation of offal about the stems. The buried forests of Oregon and Alaska, described by Newberry and Russell, are typical. Medlicott's¹²⁰ résumé of Ormiston's observations may be noticed in this connection, as they show how a forest, growing in an old soil of vegetation, may be succeeded by a marine deposit, while the stems remain erect. Excavations for a government dock were made on Bombay island off the west coast of India. In a space of about 30 acres, 382 trees and stumps were uncovered, of which 223 were erect. Some of the prostrate stems were without roots but others had been overthrown in place, for the roots were still embedded in the soil. The stumps are rooted in a thin soil of decomposed basalt and are surrounded by a stiff blue clay on which rests black marine mud, 4 to 5 feet thick. Stumps projecting above the clay into the black mud have been drilled by *Teredo*; in some cases the holes pass downward through the trunk toward the root and are filled with indurated clay. The trees are *Acacia catechu*; how far the forest extended is unknown, as no investigation was made beyond the limits of the excavation.

The opinion, that stems of trees would not endure while a considerable thickness of rock accumulates, is based on very serious misapprehension of the facts or on *a priori* reasoning. The writer has seen slender canes standing erect near the mouth of the Mississippi River, though they had been dead long enough to permit deposition of several feet of fine silt around them. Weed¹²¹ has shown that the Yellowstone Park diatom deposits cover many square miles. A typical marsh is in the Upper Geyser basin, where the waters encroached upon the timber and killed the pines, whose bare gray stems stand upright in the marsh or lie half immersed in the ooze. The diatomaceous earth is sometimes 6 feet thick and the "gaunt poles of the dead pines stand in a white powdery soil, which is evidently a dried portion of the marsh mud."

¹²⁰ G. E. Ormiston, cited by H. B. Medlicott, Records Geol. Surv. of India, Vol. XIV., 1881, pp. 320-323.

¹²¹ W. H. Weed, "Diatom Marshes and Diatom Beds of the Yellowstone National Park," *Bot. Gaz.*, Vol. IX., 1908, pp. 76-83.

Wright¹²² has described the buried forest near the Muir glacier in Alaska. This was deeply buried under gravels, over which the ice extended at a later period. The ice retreated and erosion began, which eventually uncovered the forest. The trees are of large size, mostly like those now growing on the Alaskan mountains and are in a state of complete preservation. These are standing upright in the soil on which they grew, with the humus still about their roots. Some are exposed throughout while others are shown only in part. Many are broken off at from 5 to 20 feet above the roots; Wright thinks this fracturing due to cakes of ice, that being indicated by scars on the trunks. Russell,¹²³ writing about a portion of Alaska farther west, states that the Yahtse River, issuing as a swift current from beneath a glacier, has invaded a forest at the east and has surrounded the trees with sand and gravel to a depth of many feet. Some of the dead trunks, still retaining their branches, project above the mass, but most of them have been broken off and buried in the deposit. Other streams east from the Yahtse have invaded forests, as is indicated by dead trees standing along their borders. Where the deposit is deepest, the trees have already disappeared and the forest has been replaced with sand flats. The decaying trunks are broken off by the wind and the stems are buried in prostrate position. Nordenskiöld,¹²⁴ in discussing the distribution of trees in the Yenesei region says:

"Besides these there are to be found in the most recent layer of the Yenesei tundra, considerably north of the present limit of actual trees, large trees with their roots fast in the soil, which show that the limit of trees in the Yenesei region, even during our own geological period, went farther north than now, perhaps as far as, in consequence of favorable local circumstances, it now goes on the Lena."

Resistance to Erosion.—The opinion, that trees would be uprooted and carried away by the strong current of a flood, is not well-supported as a generalization. The instances cited from Russell and Wright would seem to suffice in refutation and the writer has dis-

¹²² G. F. Wright, "Ice Age in North America," 1889, pp. 57-59.

¹²³ I. C. Russell, "Second Expedition to Mount St. Elias," Thirteenth Ann. Rep. U. S. Geol. Surv., 1893, Pt. I., p. 14, Pl. XII.

¹²⁴ A. E. Nordenskiöld, "The Voyage of the Vega," p. 287.

cussed the matter somewhat in detail elsewhere.¹²⁵ But it may not be amiss to cite some additional evidence showing that floods and torrents are almost powerless against living vegetation. In the summer of 1895, the writer was marooned during three days by a flood on the Little Wichita River of northern Texas. The flood was widespread, affecting also the area of the Brazos River. It came abruptly, so that in a single night, the petty streams, flowing at 30 to 40 feet below the general level, filled their little valleys and overflowed; the parched area of the preceding day was covered with water more than hub-deep in many places. The current was extremely rapid; by mistake of the guide, the party were caught in it on one stream and narrowly escaped being swept away with the horses and the heavy conveyance. Within 2 miles of the city of Archer, the flood had invaded an extensive area, covered with trees and shrubs. Rapid outside, the movement was insignificant within this wooded area, the trees and shrubs, though not dense, being as efficient in checking the motion and in breaking up the current as is *débris* in a mountain forest. After cessation of rain, the flood subsided almost as quickly as it had risen. A ride of 60 miles over the area affected by it gave ample opportunity for studying the effect. The roads and sandy places were gashed and gullied; cultivated fields in the line of the torrents, one eighth to half a mile wide, were swept clean of the thin cover of soil, but where the surface was protected by grass the destruction was unimportant. Trees and shrubs, except those standing on loose material, were uninjured, while in extensive clumps of bushes there was no evidence of disturbance, aside from an accumulation of *débris*, deposited where the current first reached the plant-obstruction. The fierce current was powerless against trees, even against the clumps of bushes.

Reade,¹²⁶ writing of floods on the Senegal and Gambia Rivers, says:

"If a boat was to be moored in the rivers to the top of an acacia tree just projecting above the water, you would find it afterward in the dry season hanging forty feet above your head."

¹²⁵ See "Formation of Coal Beds, II.," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 520-546.

¹²⁶ W. W. Reade, "Savage Africa," New York, 1864, p. 363.

After these violent floods have abated, the forests are seen practically uninjured by their brief submergence. The remarks by Harris¹²⁷ are in place here. The Hawash River rises in the Abyssinian highlands at 8,000 feet above sea-level. In the dry season, it can be forded easily but during the rainy season it is often converted into a fierce torrent inundating the broad valley, which is covered with trees and dense undergrowth, through which the explorer makes way only with great difficulty. When the expedition approached this river, it was very evident that there had been a flood, as "pensive willows that drooped mournfully over the troubled current, were festooned with recent drift, hanging many feet above the level of the abrupt banks." The condition was very similar to that observed by the writer in going by steamboat from San Francisco to Sacramento, almost 50 years ago. He was perplexed by the presence of clumsy *débris* in branches of trees at about 15 feet above the water. This marked the level of the floods.

The Ohio Valley flood of March-April, 1913,¹²⁸ was one of the most disastrous recorded. The damage to the towns of southeastern Ohio, as stated by Horton and Jackson, was almost 147,000,000 dollars, 36,000 buildings were flooded or destroyed and 220 bridges were carried away. The report is illustrated by 22 plates, showing conditions during and after the flood in several large cities, which suffered most severely. These show that trees in the streets resisted not only the current but also the *débris* carried by the water; houses and timber were piled around the trees and even the telegraph poles. One of the photographs gives ample proof that this was no gentle backwater overflow but a typically torrential movement.

The tenacity with which trees resist removal by floods is, to use a moderate term, remarkable. For many years the writer has ridden annually for more than 200 miles along the Connecticut River in June and September. In many places, trees cover the face of first terrace, extending frequently to within 18 inches from the line of low water. The terrace or "first bottom" is composed of uncon-

¹²⁷ W. C. Harris, "The Highlands of Ethiopia," Amer. ed., New York, 1844, pp. 94-96.

¹²⁸ A. H. Horton and H. J. Jackson, U. S. Geol. Survey, Water Supply Paper, No. 334, 1913.

solidated river drift, which where unprotected is attacked energetically by the current. The trees along the lower portion of the bank have roots almost horizontal, as the wet ground is little more than a foot below the collar. In very many cases the roots are exposed to a distance of two to three feet from the trunk, the loose material originally surrounding them having been removed. Several of these trees have been observed each year, during ten years the exposed portion has increased steadily, but the trees have continued to grow and apparently they are as solidly fixed as at first.

But in the sands under and over peat deposits as well as in rocks contemporaneous with such deposits, one finds logs, even tree stems with attached roots. Rivers undercut their banks, trees and plant *débris* fall into the water and are transported. Some of this material is carried to the sea, there to decay, but some is dropped in shallows or stranded on the river plain during subsidence of the flood, to be covered by deposits brought by succeeding floods.

Contemporaneous Erosion.—Little rivulets are seen in the smaller bogs, but great swamps, in which peat is accumulating, are more or less imperfectly drained by rivers with sluggish flow. The streams are subject to floods, during which they bring down more or less organic material mingled with plant *débris*. Much of this is deposited in the channelway and much of the rest is spread over the flooded portion of the swamp. Sometimes an obstruction dams the stream and diverts its course, leaving below the dam a stagnant pool, which in time becomes concealed by peat; but the story is revealed when a drainage canal is cut, for the half-filled channelway is shown by a "roll" in the underclay. The drainage system is often distinct in a buried bog. Lorie's¹²⁰ observations in the peat region of Holland-Belgium prove that the channels of large rivers have been filled with sediment and that these are traceable easily when the records of borings have been platted.

Banks of the intersecting streams are irregular, as plants spread out into the water, often becoming floating fringes. When the channelway is filled gradually by deposit of inorganic matter, the fringes are not torn away but are enveloped in approximately normal

¹²⁰ Cited in "Formation of Coal Beds, II," *Proc. Amer. Phil. Soc.*, Vol. L., pp. 617-619.

position, to be exposed as irregular strings of peat when laid bare by a drainage canal. If, however, the filling be abrupt and violent, masses of the peat are rubbed off to be embedded in the sand, while the adjacent portion of the bog is very apt to show crushing or folding.

Filled channels occur frequently in rocks associated or contemporaneous with the peat deposits. The Missouri and Mississippi Rivers have shifted the channels at many places and the abandoned "ox-bows" in numerous instances have been filled with material different from that of the banks. The rivers of the Gran Chaco of Paraguay and Argentina flow in constantly shifting channels, the older ways becoming filled to be exposed by a new change in direction of flow. A. Geikie¹³⁰ has described several cases of channels in the drift beds of Scotland, eroded and refilled during the Glacial period. Others have been noted by J. Geikie and by J. Croll.

Some Chemical Features of Peat.—It is well known that mature peat, when first taken out, is plastic; but when thoroughly dried it is no longer plastic. The same effect is said to be produced by freezing. It is evident, as said by v. Gümbel more than thirty years ago, that peat contains some substance, which is soluble in the fresh condition but is insoluble when dried. Microscopical study of mature peat shows that the minutely divided vegetable matter is accompanied by an amorphous substance, sometimes so abundant that the fragments appear to be cemented by it or even to be embedded in it. The earliest reference to this substance, known to the writer, is that by Reinsch,¹³¹ who stated that in the Fichtelgebirge there are two kinds of peat, Rasen- and Pechtorf. Rasentorf occurs in thick deposits, 2 to 12 feet, but Pechtorf is in thin layers, as shown in his material from near Rautengrün on the left bank of the Eger river. The latter feels damp, almost greasy, is about twice as heavy as Rasentorf, has lustrous, brown-black surface and consists of roots embedded in an almost black substance.

Definite information respecting this material seems to be due

¹³⁰ A. Geikie, "On the Glacial Drift of Scotland," *Trans. Geol. Soc. Glasgow*, Vol. I., Pt. II., 1868, pp. 65 ff.

¹³¹ H. Reinsch, "Ueber den Torf des Fichtelgebirge," *Journ. f. pr. Chemie*, Vol. XVI., 1839, pp. 489-495.

to Doppler,¹³² who stated that he had received from Salzburg, in Tyrol, about 15 pounds of a black gelatinous substance, which had been obtained near Aussee in a peat bed, about 10 feet thick. It occurred in layers at 6 to 8 feet from the surface and it had been rejected as worthless. Schrötter,¹³³ who studied this chemically, ascertained that, dried at 100° C., it lost 78.5 per cent. of water and became a hard mass with conchoidal fracture and vitreous luster, resembling greatly the pitch obtained by distillation of coal tar. Dried at ordinary temperature, about 18° C., it parted with 66.22 per cent. of water. The wet gelatinous material lost 14.6 per cent. to caustic potash, equivalent to 68 per cent. of the dried material, but when dried, it lost nothing to the potash solution. Hydrochloric acid precipitated from this solution a brown substance which, dried, contains; Carbon, 48.06; hydrogen, 4.98; nitrogen, 1.03; oxygen, 40.07; ash, 5.86.

If ash and nitrogen be ignored the composition is, compared with that of cellulose,

Carbon	51.59	43.24
Hydrogen	5.34	6.30
Oxygen	43.03	50.56

The presence of ammonia is evident when a fragment is boiled with caustic potash. He recognized in this gelatinous substance simply a more than usually homogeneous peat, owing its gelatinous character to the great quantity of absorbed water.

At the same meeting, Haidinger¹³⁴ discussed the mineral relations of this material, to which he assigned the name, Dopplerit. It is amorphous, but thin sections, under strong power, show the presence of fine fibers in the mass. One of the pieces received from Doppler enclosed fragments of unchanged peat, in which *Phragmites communis* was recognized. Haidinger believed that this structureless peat is the beginning point of the whole series of changes, which up to that time had been wholly conjectural.

¹³² Doppler, "Ueber ein merkwürdige in Oesterreich abgefundene gelatinöse Substanz," *Sitz.-ber. k. Akad. Wiss. Wien*, 1849, Bd. 3, Abt. 2, p. 239.

¹³³ Schrötter, the same, pp. 285-287.

¹³⁴ W. Haidinger, the same, pp. 288-292.

Von Gümbel¹³⁵ made an elaborate study of Dopplerit in 1858. He found that the Berchtesgaden dopplerite differs in some respects from that of Aussee. After drying in air, it gives off 12 per cent. of water at 100° C.; when heated to red heat in a closed vessel, it yielded 66.33 per cent. of non-coherent coke, retaining the form of the original fragments. The ash is but 1.67 per cent. of the dried material and consists mostly of lime. Treated with absolute alcohol, it yields a considerable quantity of resinous matter, which v. Gümbel thinks consists of two resins. The variability of composition at different localities leads him to believe that dopplerite is not a true mineral, but is merely a homogeneous peat and he suggested instead the term Torfpechkohle because of its resemblance to the Tertiary Pechkohle. The mode of occurrence at Berchtesgaden is peculiar, the succession in the pits being (a) Rasen- and Moorerde; (b) Specktorf; (c) Fasertorf; (d) Specktorf; (e) Fasertorf with roots; (f) gray marl; (g) calcareous pebbles. (f) is almost impervious to water. The Torfpechkohle is found chiefly between (d) and (e), but (c) contains much of it in irregular streaks. Two vein-like branches pass upward from the main deposit overlying (e) and continue through the higher benches into (a). He is convinced that the material was soft and that under pressure it flowed into crevices. This feature suggested that plant materials were softened as one step in the conversion into coal.

Kaufmann¹³⁶ received specimens of a lustrous black coal, occurring in a peat layer at Obburgen in Unterwalden, Switzerland. It agrees with dopplerite in all essential features. The material was from a Hochmoor, where it was found at 12 to 14 feet below the surface and in masses 6 inches to a foot thick, embedded in the black peat; but it often occurs as veins, streaks or nests. When fresh, it is gelatinous but it becomes hard on drying; it is odorless, has greasy luster and mahogany streak; softer than talc, it cracks under pressure. Examined under the microscope it is homogeneous,

¹³⁵ C. W. v. Gümbel, "Ueber das Vorkommen des Torf-Pechkohle (Dopplerit) im Dachelmoos bei Berchtesgaden," *Neues Jahrbuch*, Jahrg. 1858, pp. 278-286.

¹³⁶ F. J. Kaufmann, "Ueber den Dopplerit von Obburgen und über das Verhältniss des Dopplerit des Torf und mineralischen Kohlen," *Jahrb. k. k. Geol. Reichsanst.*, Bd. XV., 1865, pp. 283-290.

but there are some fine granules, more or less transparent, and occasional traces of cell structure. Under water, dopplerite remains unchanged for years. Once dried, it is equally stable; when wetted again, it may soften so as to show the print of the finger nail, but no farther change appears after several months.

Muhlberg analyzed four specimens, three from Obburgen and one from Aussee the original locality. In all the carbon is higher while oxygen and nitrogen are lower than reported by Schrötter. The difference was enough to induce Muhlberg to make additional study. The material was treated with caustic potash and the dissolved substance was analyzed. It is richer than dopplerite in carbon. Kaufmann finds evidence that the varying composition is due to varying extent of change in the vegetable matter. Peat examined in thin slices shows sufficiently well the organic structure but it contains bright specks, soluble in boiling caustic potash; these are very rare in young peat but are abundant as nests in mature peat. This dissolved material acts as that dissolved from dopplerite. The proportion dissolved by caustic potash increases with the age of the peat, as shown by the following results of Kaufmann's experiments: 25 to 30 per cent. from peat directly under the living plants; 54 per cent. at 3 feet below the surface, loose; 55 per cent. at 6 feet below the surface, darker, fibrous; 65 per cent. 9 feet below the surface, coffee-brown, compact, comparatively heavy. Blackish-brown, heavy, compact peat with black pitch-like streak yielded 77 per cent.

According to Billingsley's¹⁸⁷ notes, the peat of the South Marsh, 3 to 15 feet thick, is accompanied by a pitch-like substance, which occupies the spaces between the vegetable fragments.

Zincken cites von Tschudi (1859) to the effect that dopplerite is found in Switzerland near Bad Gonten in Canton Appenzell, where, beyond the depth of 9 feet, it occurs in streaks up to 5 inches thick. Humus acid flows from this and hardens to Pechkohle; he cites J. W. Herz as authority for this composition of dopplerite: Water, 15.03; ash, 3.39; carbon, 57.47; hydrogen, 5.32; oxygen,

¹⁸⁷ Cited by H. B. Woodward, "Geology of Eastern Somerset," etc., 1876, p. 156.

36.25; nitrogen, 0.86. The material analyzed was air-dried; the ultimate composition as given is ash and water free.

Demel,¹³⁸ studying dopplerite from the original locality, found that it would not give up all its water at less than 120° C.; but this high temperature should not be prolonged, as decomposition begins quickly. His specimens contained no nitrogen, thus differing from those analyzed by Schrötter and Muhlberg. The ash varies little from 5 per cent. The carbon approaches that obtained by Kaufmann but is nearly 5 per cent. more than that reported by Schrötter, with also an increase of 0.4 per cent. in the hydrogen. He assigns the formula of $C_{12}H_{14}O_6$ to dopplerite. A large part of the mineral is soluble in caustic potash, from which it may be precipitated by acids. This precipitate has less hydrogen, the formula as determined by Demel, being $C_{12}H_{12}O_6$. The ash, 5 per cent., contains 72.67 per cent. of calcium oxide, equivalent to about 3.63 per cent. of the dried dopplerite, along with 12.02 per cent. of alumina and ferric oxide.

Von Gümbel in his later study, recognized the calcareous nature of the ash, which is snow-white; he thinks there may be a chemical combination of the calcareous and organic constituents.

Früh's¹³⁹ discussion was more elaborate than that by any one of his predecessors. He compared the features of dopplerite from many localities. It is present throughout some peats as brown flakes, one centimeter to a decimeter, giving a mottled appearance to the mass, which he terms Marmortorf. He found it only in Rasentorf (grass and sedge), or at the junction between Rasen- and Hochmoor (*Sphagnum* peat); that is to say, only in peat rich in water, a condition which favors ulminification. Dopplerite and peat are not separated sharply, there being always a passage zone. Evidently the dopplerite was fluid; it is associated frequently with a twig or root, along which it flowed; sometimes, it is in thin sheets; it may fill preëxisting cracks in the peat or in the underlying materials. The calcareous ash led him to believe that it is present in the Rasentorf because that thrives in calcareous water, whereas *Sphagnum* does not; at the same time, *Sphagnum* is convertible into

¹³⁸ W. Demel, "Ueber den Dopplerit von Aussee," *Sitz.-ber. k. Akad. Wiss. Wien*, 1883, Bd. 86, Abt. 2, pp. 872-878.

¹³⁹ J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883, pp. 64, 68, 69-72.

dopplerite, for Fröh saw dopplerite of sphagnum origin at the junction of Hoch- and Rasenmoor, where the water was very abundant. He objects very strongly to regarding the material extracted by caustic potash as the true dopplerite; he believed the mineral to be an ulmin product; the potash dissolves both ulmin and humin products. Dopplerite, according to Fröh, is most abundant in the lower portions of a deposit, but the microscope detects flakes of ulmin-like material throughout the mature peat. It is well to recall here the fact observed by C. A. Davis in Michigan and by Dachnowski in Ohio, that *Sphagnum* is indifferent to the character of the water, limy constituents not interfering with its growth. Equally, Rasenmoors do not require calcareous waters, for the water of the Rhine and of the Meuse is thoroughly fresh. Kinahan, in 1861, referred to the tarry fluid which trickled from an Irish bog—evidently dopplerite.

H. L. Fairchild in 1881 and Lewis in 1882 described a dopplerite-like substance obtained near Scranton, Pennsylvania. Lewis's¹⁴⁰ description is the more in detail. This substance is in swamp muck at the bottom of 8 to 10 feet of peat and occurs in irregular veins. It is black and jelly-like when fresh, but on exposure becomes tougher and more elastic. Caustic potash dissolves it. Analyzed by J. M. Stinson, it proved to contain: Carbon, 28.989; hydrogen, 5.172; nitrogen, 2.456; oxygen, 56.983; ash, 6.400. The formula as determined from the analysis seemed to be $C_{10}H_{22}O_{10}$. There is little combined nitrogen as the quantity of ammonia is small.

Foster¹⁴¹ studied a substance which appears to be very closely allied to dopplerite. The deposit is in northwestern New Mexico along a broad "wash," draining into the canyon of the Chaco River. Its existence was indicated first by a Navajo Indian, who said that wherever the Indians had sunk wells within an area, 10 miles long and of considerable width, they had encountered this material. The collector reported that normally it underlies clay and soil, but sometimes the clay is absent. At the first test pit, clay is absent and the

¹⁴⁰ H. C. Lewis, "On a New Substance Resembling Dopplerite, from a Peat Bog at Scranton," *Proc. Amer. Phil. Soc.*, Vol. XX., 1882, pp. 112-117.

¹⁴¹ W. Foster, "A Remarkable Carbonaceous Deposit near Putnam, New Mexico," *Econ. Geol.*, Vol. VIII., 1913, pp. 360-368.

deposit, there liquid, was reached at 3 feet from the surface. It ran into the pit as rapidly as it was baled out. Four miles away on the same wash, a second pit reached, at 3 feet, one foot of clay resting on the deposit, more than 10 feet thick, the bottom not reached. At this locality, the substance has the consistence of gelatin, becoming denser with increasing depth. Dried, it is black, brittle, hard and, when powdered, resembles coal dust. In two trials, the material yielded 59.69 and 53.74 per cent. of water. Burned at a low temperature, it left 53.53 per cent. of ash, containing 3.03 of lime and 9.39 per cent. of soda. Ignoring the ash, the composition is: Carbon, 56.04; hydrogen, 6.76; nitrogen, 2.04; oxygen, 35.16, which approaches very closely to the composition of dopplerite analyzed by Herz, Kaufmann and Demel. The ash is apparently a silicate of aluminium and sodium; it is very finely divided and shows no trace of diatoms; Foster suggests that it may be chiefly disintegrated soda-feldspar. Jeffrey¹⁴² examined the substance under the microscope; he found no trace of organic structure but crystalline mineral matter is present.

It is certain that peat contains an amorphous substance derived from the vegetable matter. This, originally more or less soluble, becomes insoluble when deprived of its water. The quantity is small in the newer peat but increases downward, being most abundant in the mature peat, where in many cases the vegetable fragments appear to be embedded in it. Its composition is variable, being dependent, apparently, upon the extent of chemical change in the plant material.

Composition of Peat.—In all works treating of general geology, one finds tabular comparison of the fossil fuels, based on the average of a great number of analyses. One may not deny the utility of an "average," when the averaged analyses are all from one mine on a bed of coal, the desire being to ascertain the general grade of the material as shipped. Yet even in that case, the defects in the method become painfully evident to the man, who having purchased on the basis of the average, receives coal from the less desirable portions of the mine. "Peat" is a generic term including products

¹⁴² E. C. Jeffrey, letter of December 19, 1914.

of vegetable matter undergoing a chemical change which differ in composition according to the extent of that change, according to the nature of material and according to the conditions under which the change was made. Many matters have to be considered; if these be ignored, the comparison is worthless.

All writers on peat deposits have called attention to the fact that a notable physical change is observable as one follows the peat downward from the surface, the disintegration of vegetable matter increasing so that in the great mass of the mature peat, little trace of organic matter can be recognized by the unaided eye, while in many respects the lower portion bears much resemblance to brown coal. The specific gravity increases with this change. Mills and Rowan¹⁴³ state that young Hanoverian peat has the gravity of 0.113 to 0.263, whereas that of the maturer peat is from 0.639 to 1.039. The chemical change is gradual but more and more marked with increase of depth. Cornet¹⁴⁴ has given three illustrative analyses as follow:

	C.	H.	O.	N.	Ash.
Surface.....	57.75	5.43	36.06	0.80	2.72
Two meters and one half.....	62.02	5.21	30.67	2.10	7.42
Four meters and one half.....	64.07	5.01	26.87	4.05	9.16

The ultimate composition is calculated ash and water free. The extraordinary increase of nitrogen in the lowest portion may be due in part to the presence of some plankton materials. Jentzsch¹⁴⁵ says that in the province of Preuss, the peat deposits vary in thickness from a few inches to 17 meters. The composition of a peat used for fuel is, water free: Carbon, 56.90; hydrogen, 5.54; oxygen, 31.88; ash, 5.66. In his later publication he compares peat from several localities in the same province, thus:

¹⁴³ E. J. Mills and F. J. Rowan, "Fuel and its Applications," 1889, p. 18.

¹⁴⁴ J. Cornet, "La formation des Charbons et des petroles," Extrait de l'ouvrage, *Geologie*, T. III., p. 25.

¹⁴⁵ A. Jentzsch, "Die geognostische Durchforschung der Provinz Preussen im Jahre 1876," *Schrift. k. Phys. Okon. Gesell. Königsberg*, Jahrg. 17, 1877, pp. 120, 122; "Ueber die Moore der Provinz Preussen," the same, Jahrg. 19, 1878, pp. 128-131.

	C.	H.	O.	N.	Ash.
Surface peat.....	49.90	5.80	42.80		3.50
Denser peat.....	57.50	6.90	31.87	1.75	2.08
Dense peat.....	62.15	6.29	27.20	1.66	2.70

Mills and Rowan¹⁴⁶ have given analyses of surface and dense peat from three localities in Ireland,

	C.	H.	O.	N.
Surface peat.....	58.694	6.971	32.883	1.451
"	59.920	6.614	32.207	1.258
"	60.018	5.875	33.152	0.954
Denser peat	60.476	6.097	32.546	0.680
"	61.022	5.771	32.400	0.807
"	61.247	5.616	31.446	1.690

In the region whence these samples were taken, the growth of peat has been very slow during a long period, so that the surface peat, or rather, that from near the surface has undergone much greater change than that in similar position within areas where growth still continues. The same authors give results obtained by Woskresensky who analyzed Russian peat, which evidently came immediately under the growing surface; it contained about 41 per cent. of carbon with 54 per cent. of oxygen and nitrogen.

Mulder¹⁴⁷ analyzed fuel peats from localities in Holland and found the carbon varying from 59.27 to 61.05 per cent. and the oxygen from 32.50 to 34.71 per cent.

Zincken¹⁴⁸ has given the results of two analyses of Schieferkohle from Utznach, in Switzerland; the first is of the ordinary material, but the second is of a dense coal, hard, almost black and with conchoidal fracture;

	C.	H.	O.	N.
I.....	55.27	5.70	36.84	2.19
II.....	56.04	4.70	36.07	2.19

¹⁴⁶ "Fuel and its Applications," p. 20.

¹⁴⁷ G. J. Mulder, "Ueber das arabische Gummi, die pectische Säure und die Zusammensetzung der Torfarten," *Journ. f. pr. Chemie*, Vol. XVI, 1839, p. 246.

¹⁴⁸ "Physiographie der Braunkohle," p. 24.

If one may make a suggestion on the basis of these results, it would seem as though mere pressure has had little influence here, for the hard Schieferkohle of Utnach contains much less carbon than is found in some mature recent peats.

Von Ammon¹⁴⁹ has published an analysis of Schieferkohle from Grossweil in Bavaria, which, reduced to pure coal, shows: Carbon, 60.59; hydrogen, 4.86; oxygen and nitrogen, 34.55. The ash is 8.21. This coal, according to v. Ammon, is to be regarded as an earthy brown coal with inclusion of lignite ("bituminous wood"). It is of the same age as the Utnach Schieferkohle. C. A. Davis has given a long series of analyses from American localities, to which reference will be made in another connection. It suffices here to note that in four samples, with ash varying from 3.84 to 6.69, the carbon varies from 51.8 to 59.5 and the oxygen from 41.4 to 32.6, the determination being on basis of pure coal.

Peat, according to its age and its place in the deposit, may vary in carbon-content from much less than 50 per cent. in the upper portion to more than 64 per cent. in the mature portion, the calculation being on basis of the pure fuel. The more mature the peat, by so much the more it resembles brown coal in chemical and physical characters.

Nitrogen is present in all peats, of which analyses have been published. The analyses by F. M. Stanton, which have been tabulated by Davis,¹⁵⁰ make this clear for the United States. The quantity bears no relation to that of the ash. Peat from Leon county, Florida, has 4.28 of ash and 2.30 of nitrogen, while another from Lake county in the same state, has 21.94 of ash and 2.53 of nitrogen. One from Connecticut with 45.31 of ash has 1.92 of nitrogen, while another, with but 3.98 of ash, has 1.48 of nitrogen. Sulphur is always present, sometimes in sufficient quantity to be utilized. It and nitrogen are original constituents and are not due to the transported matter.

Study of ash in peat affords some insight into the conditions prevailing during growth. The mineral content may be original, that is, derived from the plants themselves, or it may have been

¹⁴⁹ L. v. Ammon, "Bayerische Braunkohlen," etc., 1911, p. 10.

¹⁵⁰ C. A. Davis, "Uses of Peat," pp. 186-203.

introduced by wind or running water. When the deposit has been protected from influx of silt, the ash may be less than 2 per cent. of the dried material; but there is every gradation from that percentage to shale, clay, or sand with merely a trace of vegetable matter. Such variations are commonplace in upland bogs and are illustrated by one in Ohio, recorded by Dachnowski, which had more than five times as much ash on the shallow border as in the deeper portions. Analyses published in European works are too commonly of material from localities where peat is dug, where it is of proved economic value; so that one is liable to suppose that peat with less than 10 per cent. of ash predominates. It would appear, however, that a much poorer grade of peat predominates, except where, in lowland areas, checking of streams at the borders causes dropping of the load or where a dense protecting fringe of plants, like the "cane brakes" of the Mississippi delta, act as filters. The analyses by Stanton in C. A. Davis's work are of samples from many localities in 8 states. Practically all of them were taken from previously unexplored deposits and, being collected according to the official method, they represent the whole thickness. A comparison of the results shows that the peat from

24 localities	has less than 5 per cent. of ash.
74 localities	has less than 10 per cent. of ash.
28 localities	has less than 15 per cent. of ash.
28 localities	has less than 20 per cent. of ash.
28 localities	has less than 30 per cent. of ash.
20 localities	has less than 40 per cent. of ash.
43 localities	has more than 40 per cent. of ash.

The lowest percentage is 1.53, which is less than that of the plants: only 98 samples show less than 10 per cent., while 147 show more, a vast preponderance of worthless material. The analyses, tabulated by Dachnowski,¹⁵¹ are from 61 localities in Ohio; none is below 3 per cent., 14 are below 10 per cent., while 12 are above 20. When one considers that the samples, in all cases cited, were taken because the peat appeared to be such as might be utilized, it is evident that good fuel peat is only a small part of whole now existing.

¹⁵¹ A. Dachnowski, "Peat Deposits in Ohio," pp. 366, 367.

The composition of the ash depends on the character of the plants and on that of the rocks over which the streams flow. Potash and soda are usually present, but in small quantity as their salts are soluble and easily removed. Lime, iron, alumina and silica remain. Mills and Rowan¹⁵² have published 27 analyses by Kane and Sullivan, giving composition of ash from Irish peats. In these the lime varies from 12.432 to 45.981 per cent of the ash. Dachnowski gives analyses by J. W. Ames from 12 localities in Ohio, which show the lime varying from 2.210 to 4.529 per cent. of the ash. When one considers the notable quantity of certain conifers in peats, the low percentage of lime is a little perplexing; in most good peats it is only a fraction of one per cent. of the dried peat.

The action of various solvents upon peat was studied long ago by several chemists. Hunefeld¹⁵³ examined some loaf-like masses found in a peat bog near Borreby in Sweden. The proximate composition of the material was: Resin, 16.8; resinous matter like asphaltum, 40.0; wax, 2.2; coaly matter, with traces of humus, 38.0; oxide of iron with gypsum, 3.0. The material was supposed by him to be changed bread, which had been buried for about 800 years; but Berzelius objected that one cannot conceive how the constituents of bread could give a substance with this composition. Hunefeld studied numerous peats, treating them with alcohol and ether and obtaining 4 to 5 per cent. of resinous matter. There seems to be every reason to believe that his original work was correct and that he showed that resins, wax and asphaltum exist in peat, where there was no possibility that they were introduced from any external source.

Popular dread lest the draining of Haarlem lake might cause serious injury to the public health led Mulder¹⁵⁴ to examine the dense and the less dense peats separately, but by the same method. The peat was first boiled in water, which afterward was drained off, and the washed peat was dried and treated with boiling alcohol.

¹⁵² E. J. Mills and F. J. Rowan, "Fuels," etc., p. 16.

¹⁵³ Hunefeld, "Nachtragliche Bemerkung über das Brod in Torfmoore," *Journ. f. pr. Chemie*, Jahrg. 1838, Bd. III., pp. 456-460.

¹⁵⁴ G. J. Mulder, "Untersuchung über die Harze des Torfs," *Journ. f. pr. Chemie*, Vol. XIX., 1840, pp. 444-453.

When exhaustion was complete, the peat was dried and treated with Steinöl. He obtained four resins, three of which are soluble in hot alcohol, but the fourth is soluble only in the Steinöl. These are from the denser peat. Analyses of the resins obtained from the less dense peats show that they are not the same, though closely related. The quantity of resinous material seems to be greater in the lower part of a deposit; and Mulder believed that it was formed during the process of Vertorfung and not derived from the plants directly.

Smith¹⁵⁵ utilized solvents in the study of some peats from Scotland. In his memoir, he summarizes the results obtained by Hunefeld, Reinsch, Mulder and Jacobsen. He treated his peats with naphtha and alcohol and obtained, as the result of several experiments, 6 per cent. of a solid resin, black and with waxy fracture. This material has: Carbon, 73.39 to 73.55; hydrogen, 10.78 to 10.49; oxygen, not given. Smith says that such wax can be obtained from peat by distillation, but the method of solution secures the crude product as it exists in the peat. He cannot accept the suggestion that the resinous material is due to chemical change but maintains that it must be traced to the original plants themselves; the increase in proportion downwards is due to the waste of more easily decomposed materials while the resistant resins remain unchanged; but in a more advanced stage of chemical action, the resins themselves are attacked and are removed in solution.

In considering these experiments and others of similar character, one cannot determine how much is resin and how much is paraffin material. Graefe's method of treating with benzol gives an approximate determination of the waxes. Von Ammon states that the Schieferkohle of Grossweil has 3.73 per cent. of material soluble in benzol; Kraemer and Spilker¹⁵⁶ examined a considerable number of peats, treating them with benzol and in some cases with toluol. They obtained from 3 to 8 per cent. of wax, the quantity in Hochmoors being less than in other types.

¹⁵⁵ R. Angus Smith, "A Study of Peat, Part I," *Mem. Manch. Lit. Phil. Soc.*, III., Vol. V., 1876, pp. 303-331.

¹⁵⁶ G. Kraemer und A. Spilker, "Das Algenwachs und sein Zusammenhang mit dem Erdöl," *Ber. d. Chem. Gesell.*, 1912, Bd. 1, p. 1213.

It is wholly certain that the paraffins are present and that one is not compelled to go outside of the original plants to find a source for these or for the resins. The abundance of conifers leaves no doubt as to one source of the resins and waxes and these are characteristic of swamp plants. They are alike resistant to chemical change. The mode of occurrence of the New Zealand Kauri gum affords the necessary illustration for the resins. Penrose¹⁵⁷ states that this gum, a true resin, is a secretion of the *Agatha australis*, now living within an extensive area in New Zealand. The resin accumulates in large quantity on all parts of the tree and the bark, which peels off and is heaped on the ground, is saturated with it. The fresh exudations are unimportant commercially and the supply is obtained from the buried or "fossil" gum. This is found in regions now covered by the Kauri tree, in others whence the trees have been removed as well as in some where the only evidence of former forests is the presence of buried roots and other portions of the trees. At times, the Kauri forests have disappeared and have been replaced by those of other trees, the only proof of a former forest being the gum and the roots. That the antiquity of early Kauri forests is very great appears certain, for there are trees in the newer forests, which are supposed to be not less than 1,000 years old. At some localities, the gum is found in successive layers, separated by clays or sands, evidence of forests destroyed one after the other. The Senegal copal occurs under similar conditions. In many cases the resin-filled portions of the trees have been preserved, though all others have disappeared.

Distillation Products from Peat.—Lampadius published in 1839 the results of his investigation of products obtained from peat by distillation at and above the "cracking point." The experiments have been repeated many times and with similar general results. Two recent studies will suffice here. The Ziegler¹⁵⁸ process of producing coke from peat with saving of the by-products, has been tested on a commercial scale at some places in Germany. About 33

¹⁵⁷ R. A. F. Penrose, Jr., "Kauri Gum Mining in New Zealand," *Journ. of Geol.*, Vol. XX., 1912, pp. 38-44.

¹⁵⁸ C. A. Davis, "The Uses of Peat," U. S. Bureau of Mines, Bull. 16, 1911, pp. 128-142.

per cent. of good coke, containing 90 per cent. of carbon, is obtained from high-grade peat; though hard and compact, it retains the peat-structure. The tar, a mixture of the more readily condensed hydrocarbon compounds, rarely exceeds 4.5 per cent. of the dried peat, varies much in quantity and is a black viscous liquid. Subjected to fractional distillation, it yields, after separation of water, ammonia, light and heavy oils, paraffin wax, creosote and asphalt. The crude oils are said to be identical with those of petroleum in properties and appearance. The character of the tar water, containing lighter or less readily condensed compounds, depends in part on the character of the peat; the fibrous, less decomposed peats yield more methyl alcohol and acetic acid with less ammonia than those which are darker, thoroughly decomposed and structureless, which contain more combined nitrogen. This tar water contains ammonium salts, acetic and other acids as well as methyl alcohol.

The permanent gases vary with the character of the peat, the quantity of water and the temperature at which the coking is done, there being in every case a considerable proportion of air. The less decomposed peat gives the greatest quantity and the poorest quality. The variability in composition appears from two analyses, the first being from the Ziegler plant at Oldenburg and the other from that at Beuerberg; the percentages are in volumes;

	I.	II.
Carbon dioxide	27.4	15.5
Oxygen	2.2	1.1
Nitrogen	22.5	21.9
Carbon monoxide	8.6	20.4
Carburetted hydrogen	14.8	12.4
C_2H_4	1.0	
Hydrogen	23.6	
		28.6

The gas burns with a feebly luminous flame. Von Ammon¹⁵⁹ has published results obtained during destructive distillation of Schieferkohle from Grossweil, which is a well-decomposed peat with 60.59 of carbon. Two samples, each weighing one kilogramme, were tested, one retaining the woody structure, the second resembling earthy brown coal. The results are very different from those ob-

¹⁵⁹ L. v. Ammon, "Bayerische Braunkohlen," etc., p. 10.

tained by the Ziegler process. The coke is 23 to 24 per cent., the watery constituents vary little from 63 but the tar is from 1.24 in the earthy to 2.87 in the woody material. The earthy coal yielded 105.63 liters of gas whereas the woody material yielded only 97.55. The composition of the gas is

	I.	II.
Carbon dioxide	38.59	50.86
Carbon monoxide	16.80	10.60
Hydrogen	18.90	15.90
Carburetted hydrogen	0.60	1.10
C ₂ H ₄	2.10	2.10
Oxygen	0.60	0.30
Nitrogen	22.60	17.70
Sulph. hydrogen	0.21	0.74

The tar-water of number I., the ligneous type, is acid, that of the other is alkaline. The amorphous, more changed material has less acetic acid and more nitrogen combined as ammonia, but the gas shows great increase in carbon dioxide with decrease of carbon monoxide. The results may not be wholly comparable, since the lignitic, woody material may contain some constituents in greater proportion than found in the amorphous peat; the former is coniferous wood while the latter was formed in great degree from plants of wholly different type.

Summary.—Before proceeding to consideration of the Tertiary coals, it is well to summarize the facts recorded in the preceding pages.

1. The area of Quaternary and Recent peat deposits is apparently greater than that on which carbon deposits were laid down during any preceding period of similar duration; yet it is but a small part of the earth's surface, for there are vast spaces on which no peat has formed since the Quaternary began, though much of the peatless regions has been forested.

2. Peat bogs vary in size from a few square feet to thousands of square miles. The smaller deposits are due to filling of pools, ponds or lakes by plant invasion, while the more extensive deposits, those on coastal or broad rivers plains, originated, certainly in some, probably in most cases, in small, isolated bogs, which became united

by transgression. These, though continuous superficially, are not strictly contemporaneous throughout. The buried deposits of Holland-Belgium-France are continuous with living bogs on the mainland; but the buried peat, in greatest part, is older than that now exposed, as evidently the marsh crept gradually inland during the subsidence. In like manner, the great deposits formed on plains show notable variation in thickness as well as in composition. The vast peat-covered plains of Alaska and Siberia have a contemporaneous top layer, but the underlying portions of the deposits are probably very far from being strictly contemporaneous.

3. The condition prerequisite to formation of peat is an abundant supply of moisture with sluggish drainage; this does not mean that alternating wet and dry seasons are necessarily preventive. If the supply of moisture suffice to keep the main mass moist, the loss during the dry season is more than made good by growth during the wet season, as shown by some tropical swamps. This condition of moisture depends greatly upon the topography, which determines the character and extent of drainage. Temperature is important as affecting rapidity of growth. In Spitzbergen, 78 degrees, North Latitude, peat covers considerable areas but the deposits are very thin, for the season of growth is brief and the temperature is always low. But the growth is much greater in the Alaska region to beyond the Yukon, where the plane of perpetual frost is within 6 to 14 inches from the surface. The atmospheric temperature during the summer is higher and the winter temperature is lower than in Spitzbergen as the climate is continental, not insular. In the cold regions, decomposition is less advanced than in lower latitudes and the accumulation is of vegetable matter rather than of peat, properly so-called. In the tropical areas, where the topography permits proper moisture conditions, it is evident that prolonged high temperature in no wise prevents accumulation but rather encourages it by favoring rapidity and density of vegetable growth. Koorders, Molengraaff, Harrison, Kuntze and others have described the vast deposits in tropical East Indies and South America. Harper, Hilgard, Lyell and others have described subtropical peat deposits in the United States, while many observers have written about the

temperate zone peats of North America and Europe as well as about those of the arctic and sub-arctic areas. In North America, the passage from subtropical peats of Florida to those of the subarctic areas is gradual; the plant-life changes, but the peat varies little in character. The fact is certain that in the tropics as in the temperates, peat accumulates where the necessary conditions exist and that it does not accumulate in either when those conditions are wanting.

4. Peat may be derived from any land plant, but ordinarily the flora contains many types. The constituent plants vary at the several horizons in a deposit, but for the most part the peat does not consist of any one plant or class of plants. Occasionally a layer consists of remains of a single species, but the occurrence is comparatively rare. The peat-making forms are not the same at all localities. In northern Europe, certain mosses, chiefly *Sphagnum*, are the important constituents in the upper layers, so also in some parts of North America; but there are considerable areas in both regions where mosses are either wanting or are wholly unimportant. Sedges have been the efficient peat-producers in much of the north temperate, even at some tropical and subtropical localities. But there is no limitation; conifers, palms, deciduous trees, mosses, sedges, in a word, any water-loving plant or any plant preferring a slightly acid soil will yield peat under similar conditions; the soft parts become a pulp but the harder parts change more slowly. More than 100 years ago, Al. Brongniart called attention to peat in Holland composed of leaves of conifers and Reinsch, almost 75 years ago, observed similar peat in Germany; the formation of peat from offal of oaks and conifers is a familiar phenomenon in the Rocky Mountain region.

In Tierra del Fuego, where conditions are subarctic, the chief peat producer, according to Darwin, is a sedgelike plant, *Astelia pumata*; in the Falkland islands, every plant is a peat-maker while at Chiloe, *Astelia pumata* and *Donatia magellanica* make up the mass of the peat. The Nile Sudd consists chiefly of sedges and grasses; in Florida, not only conifers of various types but also grasses and sedges contribute, and even the hyacinth has become important. But they all give peat; the sedge-conifer-moss peat of Germany is almost

the same in composition as the peat from Sumatra and other islands within the tropical regions. The differences in composition of peats from these widely separated localities are little greater than those observed in the several benches of any thick deposit.

5. The felted structure of the peat is not due to any special character of the plants, for it is present in forest litter. The extent of chemical and physical change increases downward in a deposit. At the top of a growing bog, one finds living plants, but within two or three inches, the mass consists of dead material, slightly changed in color but with small increase in percentage of carbon. Lower down, the organic structure becomes less and less distinct and, at length, the whole mass is, to the unaided eye, merely a pulp, in which are embedded fragments of wood and occasional leaves. The condition is described by both Darwin and Thomson for southern latitudes. The former, in writing of Tierra del Fuego, says that *Astelia pumata* constantly produces new leaves on the growing stem, while the older ones decay. Traced downward into the peat, the old leaves can be seen in all stages of decomposition until the whole has been blended into a confused mass. Thomson says of the Falkland peat that roots of *Empetrum*, *Myrtus*, *Caltha* and sedges can be traced downward for several feet, but finally all structure is obliterated and the whole is reduced to an amorphous, structureless mass. Examined under a glass, this pulp proves to consist mostly of plant remains, fragmentary and irregular in form. The unequal action of decomposing agencies causes this peculiarity of form, which might suggest to some that the plant remains had been subjected to attrition during transport by running water. But the material is of *in situ* origin, and all stages of change are distinct.

The several parts of plants are affected differently and not all plants are affected alike. *Hypnum* appears to be especially resistant, for layers of the almost unchanged moss have been found underlying a considerable thickness of pulpy material. The soft parts of plants are reduced quickly and the wood of most deciduous trees is reduced but little less rapidly. The wood of oak and conifers remains unaffected for long periods, practically the only apparent change being increase in hardness. The bark of nearly all trees

persists even after destruction of the other portions, so that the flattened bark becomes, as it were, an imprint on the pulp.

6. The stages of growth in peat deposits depend very largely on the original topography of the area. In the filling of water-basins, the first stage is formation of mud on the bottom. This may be calcareous, formed by *Chara* and mollusks, and may hold remains of water animals, pollen, spores, freshwater algæ and vegetable remains of other sorts, floated in by streams or blown in by the wind. If streams carry detritus and the water have low calcareous content, the bottom is covered eventually by fine silt with similar organic content; but if the pond be free from influx of detritus and calcium salts, the first deposit is a mud consisting of remains of aquatic animals, freshwater algæ with spores and pollen blown in by the wind. This is the Lebertorf stage, the Sapropel stage of Potonié. This material, in some cases, increases with great rapidity, and the water, at length, becomes so shallow that certain types of aquatic plants take root and the formation of normal peat begins; first, the plants rooting under several feet of water; then reeds encroach and the rushes and sedges advance to form a floating cover, on which shrubs and even trees take root along with ferns and, in many localities, eventually *Sphagnum*. The trees advance, conifers first, to be followed by deciduous forms of the forest type when the surface becomes dry to a depth of a foot or more. Throughout, one finds abundance of spores and pollen grains, and occasionally a lens of Lebertorf occurs, marking the site of a pool or pond in the growing mass. This, in a general way, is the succession as worked out by the early observers and confirmed by all students during the last third of a century.

The succession may differ somewhat in deposits formed on plains bordering great rivers or on coastal areas. These begin frequently, perhaps generally, in small, shallow ponds, caused by local obstruction of drainage and expanded by transgression, which led to union of many small deposits. The Lebertorf stage could exist in the original small spaces but not in the newer portions formed during transgression, except where local ponds originated in the peat.

7. The accumulation of peat has been continuous in few locali-

ties; even small deposits show pauses like those which characterize those of greater extent. Many times a cyclical order is distinct and the deposit is divided into benches. The process was interrupted again and again, so that the surface became dry enough for growth of trees, not merely of conifers but, in some cases, even of deciduous trees of forest type. Sometimes such pauses were of long duration as is shown by the age of the trees. The forest growth was frequently very dense, for the peat is loaded with stumps and broken stems. A considerable proportion of the trees were overturned, perhaps by the wind, and sank undecayed into the soft pulp. The moister conditions returned, the trees were drowned and peat growth was resumed. This succession may be repeated several times in a single deposit.

The benches may pass gradually, the one into the other, or they may be defined sharply by partings. At times the parting consists of *Torffaserkohle* or mineral charcoal, mingled with extremely fine mineral matter, the residuum on the surface of peat long exposed to oxidation. Such partings mark a period of dryness without invasion by forest, during which the peat wasted. But partings of clay, sand or marl mark invasion by water carrying detritus. After a period, long or short, the surface is again covered with shallow water and peat making is resumed, the parting serving as *mur* for the new accumulation. The parting of *Torffaserkohle* and ash may be continuous with the thick parting of transported material, so that when peat making has been resumed over the latter, the process would extend over the thin parting of wasted peat. It is important to bear in mind that the thin parting is more than equivalent in length of time to the thick parting. The new peat, expanding by transgression, required a period for advance; the peat underlying the parting of transported material may be strictly contemporaneous throughout, except that the upper part is represented by the thin parting. A thick cover of detrital matter may bring accumulation finally to a close in one portion of an area while growth continues in another. Sand dunes in some localities within the United States have covered bogs of small size so that no farther increase was possible; but in the Baltic region, as shown by German and Scandinavian geologists,

dunes have covered great portions of the peat area, while other great portions have remained uncovered and in continuous growth.

8. Expansion of peat deposits by transgression has been observed in all parts of the world. Trees, still standing but killed by advancing marshes, have been described by several writers in the United States, and the process of covering the stems has been made clear in preceding pages by citations from Scottish authors. In many deposits of wide extent, the fact of transgression becomes evident only after removal of the peat for fuel or during reclamation. The stumps of the invaded forest are laid bare, their roots still fixed in the mur of the deposit, while their broken and shattered trunks are prostrate in the peat, which accumulated around the trees and destroyed them by preventing aeration of the roots. Many of these great deposits have no trees rooted in the mur in some portions, while those are abundant in other portions. The stumpless spaces mark the places where the bog originated; those with stumps and prostrate stems mark expansion by transgression on the forest area. These features are characteristic of peat deposits in the British Isles, the Netherlands, France, Germany, Sweden as well as of those East Indian swamps which have been reclaimed for agricultural purposes.

9. The effect of pressure on peat is to render it so similar physically to brown coal that the contrast with normal peat is very great. Forchhammer, Jentzsch, Nilson, Lesquereux, Goeppert and Schreiber have written in detail respecting this matter and incidental observations are to be found in writings by other authors. Even the long-continued pressure of peat itself in a deep deposit has much the same effect on the lowest layers.

10. Peat contains introduced materials of various kinds. Logs and stumps are not of these; they are merely the more resistant parts of peat-making plants, embedded in pulp from less resistant portions. Fragments of rock, sometimes angular, sometimes water-worn, have been reported from a few localities. The comparative infrequency of references may indicate rarity of occurrence, localization within the peat or the indifference of observers. The facts available are so few that any suggestion as to the origin of these fragments would be worthless. Often, there is much silt; at times, one

finds pockets of sand or clay, even of freshwater limestone. The limestone cannot be regarded as extraneous, for in all probability it was formed *sur place* in ponds within the swamp; but the other materials are of foreign origin and indicate more or less frequent flooding by detritus-laden water. In considerable areas, the quantity is so great as to render the peat worthless; in others the material is localized, as in bogs of lake or pond origin, where the peat on the borders is commercially worthless, while midway in the basin it is almost free from mineral admixture. The several benches of a peat deposit often differ notably in mineral-content, showing variations in conditions during formation. Bones of mammals, shells of freshwater mollusks, remains of beetles and other insects are of common occurrence. Peat deposits have yielded the best specimens of Pleistocene mammalia; domestic cattle are often mired in swamps and whole troops of armed men have perished in Scottish swamps during flight after battle.

11. The floor or mur of peat deposits may consist of any mineral material not injurious to plant life. Ordinarily, in swamps originating in ponds, it is composed of more or less nearly impervious stuff, clay, lake marl or Lebertorf mud. Where a deposit has increased by transgression, the mur may be shale or even sand; but in the latter case the immediate floor is apparently the cover of forest offal, the underlying sand having been rendered more or less nearly impervious by humic acid derived from the organic cover. The characteristic feature of the mur is the presence of roots belonging to peat-making plants. In original localities, where peat was formed in open areas, the roots are those of reeds, rushes water-lillies, etc.—the Rohrrichtboden of German writers being a familiar condition. Where the deposit originated in forests or encroached upon them, one finds in the mur a tangled mass of roots, oaks, conifers, alders, birches and other plants, from which the stems very commonly pass into the peat. These stems rarely extend beyond the peat cover and they are broken off at practically the same level. Where the deposit consists of several benches, each becomes in turn a mur for the next, and roots are distributed in the peat-mur as in the original clay or other mur; in each bench the stumps are cut off at or below the top of the peat.

It is seemingly probable that the pause at the close of the bench-formation was long enough to permit complete decay of exposed parts of the stems. Usually, however, the decay was complete before the end of the peat-forming period and one generally finds the upper part of the bench continuous over the tops of the stumps. The durability of stumps and of some woods is remarkable even when they are exposed, and it is much greater when they are buried in peat or in loose material containing much moisture. But decay of the wood is much more rapid than that of the bark; a stem may become hollow and the space may be filled with silt or sand holding leaves or remains of small animals, as Lesquereux, De la Beche and Potonié have shown.

12. The roof or toit of a peat deposit may be as variable as the floor. As in the latter one finds usually a gradual passage from the rock to the peat, giving a *faux-mur*, so on top one finds similarly a gradual passage from peat to rock, a veritable *faux-toit*. In this, one recognizes frequently roots, stumps and prostrate stems, remains of the forest which covered the peat. But the forest was not always present; the deposit was buried before the cycle had been completed, so that one finds, mingled with the silt or sand, leaves only of upland vegetation. The roof may be of freshwater, marine or æolian origin, it may be sand, clay, marl or limestone; the calcareous beds accumulate slowly, the others slowly or rapidly. Erect trees, rooted, are found in the roof material, but unlike those in the peat, they are not all broken off at the same height. Where engulfing material is æolian sand not deposited continuously, the trees may adjust themselves to the conditions and a long period may elapse before their death, so that the buried forest may remain in normal position and the erect trees may penetrate a notable thickness of rock, as in the Baltic provinces. When the material has been transported by running water, the accumulation may be less rapid, but enough so to kill the trees by rendering the cover too wet. The erect stems may be of any height, from mere stumps to a score or more feet and they may be surrounded by rocks of various kinds, sands or clays, in mass or in alternating layers.

Under the term "roof" may be comprehended all rocks between

one peat horizon and the next. Very often one finds in this interval alternation of land, freshwater and marine conditions. The immediate roof may be clay succeeded by sand, both of freshwater origin, but on these may rest sand or marl with shells of familiar marine mollusks. The sands frequently contain transported remains of plants, in some cases trunks of trees, prostrate, inclined or even approaching the vertical and accompanied at times by bones of various mammals, with land, freshwater or brackish water shells. The plant remains usually differ from those in the peat, and they appear to have come from undermined banks of rivers. An interesting and by no means uncommon feature is the occurrence of "soils of vegetation," bearing remains of forest growth, there being an accumulation of forest offal about and between the stumps. These mark exposed surfaces on which trees grew but where swampy, peat-forming conditions did not prevail. Erect as well as prostrate trunks are present, all enveloped by the mass of sand or clay which buried the old soil.

13. All areas in which peat accumulates have imperfect drainage; the streams are usually sluggish and are easily diverted. The peat, at times, encroaches on the channelways and eventually fills them. This condition is recognized readily when the section is exposed in excavations for reclamation canals, for the silt or sand forms a "roll" on the bottom, narrowing upward and covered by peat. Sometimes a new channel is formed during a flood and the sand-laden water tears away the peat, sometimes to the bottom, giving a "roll" in the roof, which narrows downward. Similar conditions are not rare in interval rocks between peat horizons, buried channelways being of frequent occurrence. This contemporaneous erosion marks the existence of land surfaces.

14. Plants growing on peat show great adaptability to changing conditions. Birch requires that the roots have free access to air, but C. A. Davis states that he has seen birch making thrifty growth, where the roots had been covered during two growing seasons by a foot of water. Shaler described the habits of *Taxodium distichum*, the familiar cypress of our southern swamps. Where the region is dry, the plant shows no peculiarity of root structure; but

when it grows in a swamp, where the roots are in the saturated peat, covered with water, it puts forth the curious "knees," which project beyond the water surface and provide means for aeration. If the water-level be changed abruptly, so that the knees are submerged, the tree dies, as appears in the New Madrid area, where during the earthquake of 1811, the land sank and the swampy area became a lake. *Nyssa* is provided with an equivalent protection for aeration. Conifers are found far out on the wet sedge-mat, which floats on the surface of a lake; but they grow slowly amid the untoward conditions and usually are overturned by the wind before attaining great size, as their roots are radial and very near the surface. Capp's observations respecting conditions in the White river district of Alaska are thoroughly illustrative. Peat as a soil is not repugnant to plants. The acid character of new peat is offensive to most of our deciduous trees and to many other plants; but many others, among them majestic trees both conifer and deciduous, thrive best on the damp acid material. When a bog ceases to grow, the thin upper layer becomes freed in considerable measure from the acid and the moisture; usually it is occupied quickly by the ordinary forest trees of the region, though the saturated peat may be only a foot below. The roots of these trees are radial, creeping near the surface.

15. Peat, deprived of moisture and exposed to the air, quickly undergoes change. The soluble cementing material becomes insoluble, or is removed, the mass becomes pulverulent and is apt to be swept away by the wind. The vast reclamation works, which have converted swamp areas into agricultural land, have exhibited the changes on a grand scale. The natural conclusion seemed to be that peat has been formed only to waste away. But this is an error. Peat has been formed to be preserved. Peat deposits in Scandinavia, Germany and Great Britain have existed since the Glacial period and in not a few localities they are still growing. But the growth has been interrupted many times and for considerable periods; the surface was exposed, but not long. Under ordinary conditions, shrubs and trees advance as the peat surface dries and the Waldmoor or forested bog is protected from waste. Under

other conditions, the bog may be covered by mineral materials, as on the lowland of Holland, Belgium and France, and waste by oxidation is prevented. By one method or the other the peat is preserved indefinitely; by the former method, the continued increase of peat is assured in most cases, as the forested surface again becomes marshy and peat production is resumed, to end again in a forest. This cycle has been reported again and again from peat bogs of northern Europe. The thickness of a deposit depends, other things being equal, upon the period of growth; the thickest deposits reported are those in Alaska and in tropical and subtropical regions; in those regions climatal changes have been comparatively small since the Quaternary began.

16. The composition of peat depends ordinarily upon its age, that at the bottom of a deposit not only approaches complete disintegration, so that to the unaided eye it shows no trace of organic structure, but it also is far advanced in carbon-enrichment. Yet peat from neighboring localities, where conditions seem to have been similar, may show great dissimilarity in composition; one finds strange contrasts even in the benches of a single deposit, for some may be far advanced while others consist of almost unchanged plants. This study is not concerned with the processes involved in conversion of vegetable matter, so that one must be content with the statement that some benches were buried when those processes had been checked at an early stage and that apparently no progress has been made since burial. The carbon in peat may vary from little more than 40 per cent. in the topmost layer to 49 in the next—the first used for fuel—and to 64 in the bottom portions. But in bogs where the surface growth has ceased or has been unimportant for a long period, the part immediately below the surface may have 58 to 60 per cent. Oxygen shows similar variation; there being 36 to 40 per cent. in the highest part used for fuel while the oldest, densest portions may have only 26 or 27 per cent. The ordinary fuel peat has from 57 to 64 per cent. of carbon. Density is not evidence of advanced change; the dense, hard, black Schieferkohle of Utznach, compressed by the heavy cover, has 56 per cent. of carbon and 36 of oxygen.

The ash is extremely variable even in a single deposit. Only a small proportion of the peaty material on the earth's surface is good enough for fuel and a great part of that now forming is little better than carbonaceous shale, with 25 to 50 or more per cent. of mineral matters. At times peat is found with less ash than should be expected, less than that contained in the original plants. Solution has made possible the removal; potash and soda are usually present, but in small quantity, the greater part having been removed. Lime, iron and alumina are always present, though in exceedingly variable proportions, this being due perhaps to the character of the drainage area—but this suggestion is not always satisfactory.

At many localities, the organic acids in solution have become a cementing material, more or less disseminated throughout the structureless mass, dopplerite in peat, Carbohum in Schieferkohle. In peat, it is gelatinous, but after the water has been removed it is hard and insoluble. It has reached the latter condition in Schieferkohle.

Resins, waxes and paraffins exist in peat, from which they can be extracted by solvents. They have been derived directly from the plants; there is no reason to believe that they were formed during the conversion into peat or that they were introduced from an external source.

THE TERTIARY COALS.

Tertiary coals, of the ordinary types, are termed Braunkohle in Germany and Austria but in France and English-speaking countries they are known as lignite. The passage from peat to brown coal is extremely gradual and occasionally, as indicated on preceding pages, determination of the relations is merely a matter of personal equation. In Europe generally the complex group known as brown coal has abundant points of similarity distinguishing it from the Palæozoic or "stone" coals, so that, as Mesozoic coals are comparatively unimportant, the effort there has been to ascertain why brown coal and stone coal are so unlike and to discover reasons why the former could not be converted into the latter. But in North America the condition is wholly different, for coals of all types from wood-like lignite to bituminous, even to anthracite occur at

times within a single district, in a single bed or even within the limits of a single estate. The passage from one type to the other is so gradual that chemists and geologists of North America have labored to discover some means of distinguishing them. The problem is no longer one of merely abstract or scientific interest; it is of the utmost practical importance, since within a vast area the only source of supply is in the Tertiary and Upper Cretaceous deposits. The effort is to determine distinctions which will be available for both the seller and the purchaser of fuel.

In most works, the characteristics of brown coals are given definitively. Though in mass the color may be black, yet the powdered material has a brown tint; the content of water is considerable and air-dried specimens retain 10 per cent. or even much more, so that brown coals have been termed hydrous; jointing or cleat is wanting or at best ill-defined; the water in air-drying escapes through shrinkage cracks or along bedding planes and the coal falls into small fragments; brown coals do not coke; solution of caustic potash attacks brown coal and acquires a reddish or brownish tint; brown coals contain more carbon than peat but notably less than the stone coals.

These features are characteristic of brown coals in general but they are not wholly distinctive. Some brown coals yield a black powder and some Carboniferous coals give a brownish powder; many Carboniferous coals retain more than 10 per cent. of water and there are Tertiary coals with very much less; there are Tertiary coals with very distinct cleat while there are Carboniferous coals in which cleat is very indefinite; there are Carboniferous coals in extensive areas whose included water escapes along the bedding planes and the coal breaks first into slabs and then into small fragments; a very great proportion of Carboniferous coals do not cake while there are Tertiary coals which yield good coke; caustic potash solution attacks many Carboniferous coals; the carbon-content is not definite. In fact, the passage from brown to stone coal is as gradual, chemically, as that from the growing layer of peat to brown coal.

A proper examination of this matter will be in place only after study of the Palæozoic coals. For present purposes, the classifica-

tion by Hoffmann¹⁶⁰ must answer. He recognized a gradual change in the chemical and physical character of the upper Mesozoic coals from east to west within the Bow and Belly river region of western Canada. In the eastern strip of that district, the fuels have all the characteristics of lignite (brown coal); those of the middle strip are intermediate between lignites and true coals, the latter being found in the western strip; while in the mountains, farther west, anthracite occurs. All belong to the same general horizon in the Upper Cretaceous. Reasoning from the series of analyses which he had made, he grouped the fuels into lignites, lignitic coals and coals. Lignites are fuels which, on exposure to the air, tend more or less to disintegrate and to fall to pieces; they all communicate a deep brownish red to boiling solution of caustic potash and contain 10 to 15 per cent. of hygroscopic water, sometimes even more; they do not yield a coherent coke. Lignitic coals show much less tendency to disintegration, give less deep coloration to the potash solution, have less hygroscopic water, 5 to 9 per cent., and are practically non-caking. Coals are hard and firm, give only slight coloration to the solution of caustic potash and yield a non-coherent coke by slow coking, but a firm coke by fast coking. In the relations of carbon, hydrogen and oxygen they closely resemble some British non-coking coals. This grouping is very similar to that used by the United States Geological Survey, which is, lignite, subbituminous and bituminous coal.

Coal has been found in all portions of the Tertiary column. Pliocene deposits of some economic importance have been found in Italy, Hungary, Germany, New Zealand and Alaska. The Miocene coals of Hungary, Bohemia, Germany, Bosnia, France, Spitzbergen, Iceland and Greenland as well as those of Trinidad and the adjacent portion of South America are of great extent; coal of this age has been found in Central America and occasionally in North America, but the deposits are apparently unimportant. Oligocene coals are mined extensively in Hungary, Germany and Switzerland, but they have not been recognized definitively in North America ex-

¹⁶⁰ G. C. Hoffmann, "Chemical Contributions to the Geology of Canada," Rep. Prog. Geol. Surv. Canada, 1882-4, Pt. M, pp. 1, 2, 5-8; Ann. Rep. 1888-9, Pt. R, pp. 9-18.

cept in western Canada. Eocene coals are present in Bavaria, Austria and Hungary, but, for the most part, the areas are inconsiderable. Deposits of this age in India, Java, Sumatra and Borneo are well known, while those of western North America are the main source of supply for a vast area.

Classification of Tertiary Coals.—As the Tertiary brown coals have supplied a great part of the fuel consumed in Germany and much of France during more than two centuries, they have been classified to the last degree of detail. Brongniart¹⁶¹ recognized four types, Lignite jayet, which he thought equivalent to Pechkohle, though it is evident that his reference is to the mineral jet; Lignite friable, la houille limoneuse of Brochant, regarded by him as synonymous with the German Moorkohle; Lignite fibreux, which retains the woody structure; Lignite terreux, bituminöse Holzerde, commonly known as Terre de Cologne, black to blackish brown, with fine-grained earthy fracture, mostly homogeneous, but containing embedded trunks of trees.

Zirkel's¹⁶² grouping utilized the popular names as employed in Germany: Pechkohle, compact, brittle, pitch-black, waxy or greasy luster, conchoidal fracture; approaches stone coal but is structureless; Gemeine Braunkohle, or common brown coal, compact with more or less conchoidal fracture, less hard and brittle than Pechkohle, blackish brown to pitch black, with or without woody structure, passes on one side into Pechkohle and on the other into Moorkohle, a dense mass even in structure, black with bright streaks, is closely related to Erdkohle, or earthy brown coal, which is a friable mass of dust-like more or less loosely consolidated fragments, with dull luster and earthy fracture; Lignit or wood brown coal, in masses showing texture of wood, twigs, flowers, roots, etc.; Bastkohle and Nadelkohle are merely varieties of Lignit; Blätterkohle, Dysodil and Papierkohle are finely laminated; Wachskohle contains 62 per cent. of paraffin.

Zincken¹⁶³ presented a somewhat similar classification but in such detail as to exhibit sufficiently the great complexity of the group

¹⁶¹ Al. Brongniart, "Mineralogie," T. 2, pp. 50 ff.

¹⁶² F. Zirkel, "Lehrbuch der Petrographie," Bd. I., pp. 390-392.

¹⁶³ C. Zincken, "Die Physiographie der Braunkohle," pp. 168 ff.

known as brown coal. The terms, for the most part, are those in popular use, showing that the distinction between the several members is notable. (1) Gemeine Braunkohle, in more or less hard masses, with or without trace of woody structure, brown to blackish brown, with bright streak, dull fracture, breaks into irregular angular fragments, is intermediate between Erdkohle and Pechkohle; (2) Erdkohle, earthy brittle, yellowish to dark brown, wholly amorphous, much cleft by drying, alternating bright and dull laminae, the former more common in the upper part of beds while the denser varieties in the lower part of the bed give a shorter flame. The varieties are very numerous; Schwelkohle, very bituminous, resinous, yields tar, illuminating gas and paraffin; Schmierkohle belongs in the upper part of beds and when damp feels like clay, Colnische umbra is an earthly brown coal utilized as coloring material, Russkohle, earthy, dusty, of irregular occurrence; (3) Lignit, masses of wood, more or less fossilized, passes over into ordinary brown coal, is yellow to dark brown and breaks like wood, may contain patches of Erd-, Pech- and Glanzkohle, some lignits in drying become Pechkohle. It is derived mostly from resinous trees, the stems being flattened by softening and pressure. The varieties are numerous; Bastkohle forming layers or parts of layers, more or less of bark structure belonging to *Pinus*, *Taxus*, *Alnus*, etc., Nadelkohle, bundles of tissues of palms with parenchyma removed; (4 and 5) Dysodil or Papierkohle and Blätterkohle, in very thin laminae; (6) Moorkohle contains abundance of remains of swamp plants as well as compressed woody roots, small stems, etc., usually associated with deposits of lignit and occurs in the lower portion of the bed or fills spaces between the stems; (7) Pechkohle, dense, more or less brittle, rather tender, breaks into sharp angular fragments, black brown to pitch black, dull pitch-like to greasy luster and irregular to conchoidal fracture, passes over to common brown coal on one side or to Glanzkohle on the other; sometimes it occurs in Moorkohle, while at others it includes thin to 5-inch layers of Glanz-, derived from conifer stems pressed flat; (8) Glanzkohle is dense with conchoidal fracture, is blackish with greasy, vitreous or metallic luster; sometimes it forms whole beds but it is often as-

sociated with other types and not rarely one finds laminae of Glanz-alternating with those of dull coal, giving a banded appearance to the section. This is the hardest variety of brown coal and is derived prevailingly from resinous woods. (9) Gayet or jet, dense, hard but not brittle, richly bituminous.

Von Gümbel¹⁶⁴ was satisfied with a much simpler classification. His subdivisions are Lignit, Pechkohle, typical Braunkohle, which includes all the other varieties of authors. He adds Faserkohle, the same with mineral charcoal or fusain.

Toula's¹⁶⁵ system is as simple as that of v. Gümbel, but quite different in the method of grouping. Glanz- and Pechkohle are varieties of the black coals; Moorkohle in many ways resembles peat; Blätterkohle or Dysodil and Lignit are defined by him as by other writers. All are allied closely to types of materials observed in peat deposits.

The array of terms is formidable, but the condition is less complex than it appears. A bed never consists wholly of any one type; ordinarily several kinds of coal are found in a single bed, where those most in contrast are often found in intimate association. The great variety shows sufficiently well that the term brown coal or lignite is applied to a group of substances differing in mode of occurrence as well as in chemical and physical character, among them some closely allied to peat and others which bear great resemblance to the Palæozoic coals. Owing to the great diversity in conditions, it is necessary to present descriptions of deposits in the order of their age and in some detail, reserving until the close an effort to determine the features which are in common.

The Pliocene Coals.—Descriptive notes respecting the Pliocene coals are comparatively few. Some of the deposits are on the border line between Tertiary and Quaternary, so that the age is indeterminate. Collier¹⁶⁶ discovered an area of this kind near the palisades of the Yukon River in Alaska. Bluffs of silt and gravel, 150 feet high, line the river and contain so many bones of large

¹⁶⁴ C. W. v. Gümbel, "Beiträge," etc., pp. 139 ff.

¹⁶⁵ F. Toula, "Die Steinkohlen," Wien, 1888, p. 18.

¹⁶⁶ A. J. Collier, "The Coal Resources of the Yukon, Alaska," U. S. Geol. Survey, Bull. 218, 1903, pp. 43, 44.

mammals that the deposit is known as the "bone yard." Recent land and freshwater shells as well as cones of a *Picea*, like those of the Yukon spruces are associated with them. These silts and gravels enclose beds of vegetable matter, one more than 20 feet thick, in varied stages of conversion, from pliable wood to brittle brown lignite. As a whole the similarity to recent peat is very close. Collier's description suggests that the deposits mark sites of flood-plain swamps, more or less forested and subject to overflows by floods which, like those of this day, left behind sands as well as the trees from undermined sandy banks of the river.

Haast¹⁶⁷ saw at several localities in New Zealand, deposits of lignite or "lignitic brown coal," belonging to late Tertiary or in some cases to early Quaternary. At one, the bed is 3 feet 2 inches thick and the coal retains the woody structure; at another, he measured 14 feet of brown coal while at a third, the section shows numerous beds, 2 inches to 5 feet thick, separated by fireclays, shales and porphyritic tufas. Some lignites are distinctly ancient peat bogs while others are composed chiefly of timber. Hutton¹⁶⁸ recognized undoubted Pliocene lignites at many places in southern New Zealand, especially around the margins of old lake basins and in river valleys, which existed prior to the great depression of the newer Pliocene. Occasionally, one finds well-preserved stems and usually the vegetable origin of the material is distinct to the unaided eye; but, at times, the mass is compact, brown, structureless and cannot be distinguished from brown coal. The thickness at one place is 30 feet; but "like all lignite beds" the deposits are local and not connected.

Hantken¹⁶⁹ states that in Hungary the Pliocene frequently contains lignite and that the deposits are freshwater, holding *Unio* and *Paludina*. The beds are broken by irregular partings and vary much, even abruptly, in thickness and quality. One bed has 8 benches of brown coal, in all 3.5 meters, with 7 partings of clay, the whole thickness being 6.36 meters. The lower benches are

¹⁶⁷ J. Haast, Rep. New Zealand Geol. Survey for 1873-4, pp. 14, 15.

¹⁶⁸ F. W. Hutton, "Geology of Otago," Dunedin, 1875, pp. 96, 98.

¹⁶⁹ M. Hantken, "Die Kohlenflötze und der Kohlenbergbau in den Ländern der ungarischen Krone," Budapest, 1878, pp. 341, 343, 352, 353.

harder than the upper ones. At another place, the bed consists of brown coal, 7.5 meters, clay, 0.25 meter, brown coal, 0.25 meter. The lower bench is harder and better than the upper one, which is crowded with stems of *Sequoia langsdorffii*. The roof is clay, with impressions of plants.

Von Ammon¹⁷⁰ has described the Gustav mine, near Oettingen a.M. in Bavaria, as yielding Moor- and Mooskohle with included Lignite (bituminöse Holz). This chief bed, underlying upper Pliocene clay, is from 8 to 16 meters thick and is mined in open workings within an area of about 2,000 acres (800 ha). At Schwarzenfeld, the workable coal is but 2.5 meters thick and contains not far from 16 per cent. of wood. In all cases, the observer appears to have been impressed profoundly by the resemblance of these deposits to peat beds, both in structure and in distribution.

Miocene Coals.—Marine conditions prevailed in the present coastal plain along the Atlantic in North America during the Miocene and conditions favoring accumulation of vegetable matter did not exist in the adjacent region, for no coal has been found. But the vegetation was there and swamps were on some of the streams. Berry¹⁷¹ discovered the remains of a cypress swamp near Richmond, Virginia, associated with the well-known diatomaceous earth of that region. Among the characteristic plants are *Taxodium*, *Nyssa*, *Salix*, *Quercus* and others of types familiar in modern cypress swamps. The conditions for some reason were equally unfavorable elsewhere on the continent, and no coal positively identified as Miocene has been found anywhere in economic quantity except within a petty area in California. There,¹⁷² in the Monte Diablo range, is the bed, which was mined long ago and for many years was the chief source of fuel for steamboats. The bed, as measured by Arnold, is 14 to 16 feet thick and has a dip of about 70 degrees. The coal varies greatly in quality both vertically and horizontally, specimens from some openings being, in composition, very much

¹⁷⁰ L. v. Ammon, "Bayerische Braunkohle," etc., pp. 15-21, 26, 27.

¹⁷¹ E. W. Berry, "A Miocene Cypress Swamp," *Torrey*, Vol. VIII., 1909, pp. 233-235.

¹⁷² R. Arnold, "Coal in the Monte Diablo Range," U. S. Geol. Survey, Bull. 285, 1906, pp. 223, 224.

like bituminous coal while those from others are lignitic. There is a marked variability in the percentage of ash. In burning, this coal gives off an enormous volume of smoke.

Pardee¹⁷³ has recorded brief notes respecting deposits in Montana, which appear to be on the border line between Miocene and Oligocene. They are lenticular and consist of remains of vegetation, which grew on the flats, mingled with silts from the muddy water which frequently flooded the spaces. The coal attains a maximum thickness of 7 feet, is banded, with alternating bright and dull laminae, has semi-conchoidal fracture, splits along the bedding planes and has two sets of joints, intersecting at right angles. It is usually dense and brittle, but at one mine some of the layers are rather tough and woody. The streak is brownish and the coal tends to slake on exposure. The dip throughout the region is gentle.

The Miocene coal of Greenland was discovered long ago and it has been utilized in a small way. Brown¹⁷⁴ gave numerous sections from one area. The important bed of the region explored by him is on Heer's creek, where it is double, showing coal, 2 feet 6 inches, shale, 1 foot 6 inches, coal, 1 foot. The coal is but slightly coherent, has cubical fracture and breaks down readily on exposure. Retinite is abundant in lumps from mere specks to the size of a marble. Many stems of trees are in the upper bench, but they have been replaced with chert. Somewhat later, Heer¹⁷⁵ described a bed of coal near Discovery Harbor, 25 to 30 feet thick and with extreme dip of 10 degrees. The overlying black shale is rich in plant remains; among which, as in Spitzbergen, conifers hold the first place, ten species having been recognized; with them are eight species of dicotyledons, belonging to families usually well represented in swamp floras, such as birch, elm, waterlily and other types of similar habit. Heer regards the whole assemblage as indicative of swamp origin for the deposit. The coal falls to pieces readily on exposure;

¹⁷³ J. T. Pardee, "Coal in Tertiary Lake Basins of Southwestern Montana," U. S. Geol. Survey, Bull. 531 G, pp. 11-15.

¹⁷⁴ R. Brown, "Geological Notes on the Noorsack Peninsula," etc., *Trans. Geol. Soc. Glasgow*, Vol. V., 1877, pp. 91, 95.

¹⁷⁵ O. Heer, "Notes on Fossil Plants Discovered in Grinnell Land," *Quart. Journ. Geol. Soc.*, Vol. 34, 1878, pp. 68-72.

but the analysis of an air-dried specimen by R. J. Moss as given on p. 563 of the volume just cited, shows for it a composition not far from that of a well-advanced bituminous coal: Water, 2.01; ash, 8.49; carbon, 82.97; hydrogen, 6.15; oxygen and nitrogen, 10.87.

The coal beds of Trinidad,¹⁷⁶ in the West Indies, are part of a deposit originally continuous southward in Venezuela, where it underlies an area of not less than 36,000 square miles. This region lies south from N. L. 10 degrees, where the climate during the Miocene was intensely tropical, as it still is. The newer Parian group has a fauna allied to that of the Miocene and the coal beds are in the lower members, the Caroni and the Moruga. Those of the former, from mere films to 4 feet 6 inches thick, are well shown in the interior where the upper beds, with dip of 15 degrees, are distinctly ligneous, but the lower beds, with dip of 40 to 50 degrees, are, to the naked eye, structureless. No roots were recognized in the underclays. The Moruga beds are not important; frequently they are little better than carbonaceous shale. At two places, roots were seen "rectangular to the bases of the strata." The accompanying rocks in both divisions are chiefly shales, but the Caroni contains a thick sandstone with ripple-marked surfaces.

Returning to the north, important deposits of coal¹⁷⁷ have been opened in the Miocene on Advent Bay. The bed is triple at 60 yards from the crop, showing coal, 1 foot 8 inches, clay, 2 to 4 inches, coal, 1 foot 7 inches, sand, 3 to 5 inches, coal, 1 foot.

In the upper benches the coal is hard, grayish-black, imperfectly laminated and with a somewhat conchoidal fracture. The bottom bench is black, laminated, rather lustrous and tends to be prismatic. Mineral charcoal is present in considerable quantity. In general appearance, coal from the upper benches is mostly splint-like but that from the lowest bench is remarkably like ordinary bituminous coal. Air-dried specimens contain less than 5 per cent. of water. Caustic potash solution attacks the coal throughout and acquires a very in-

¹⁷⁶ G. P. Wall and J. G. Sawkins, "Report on the Geology of Trinidad," London, 1860, pp. 41-50.

¹⁷⁷ J. J. Stevenson, "The Jurassic Coal of Spitzbergen," *Ann. N. Y. Acad. Sci.*, Vol. XII., 1895, pp. 82-95. The assignment of this coal to the Jurassic is an error; Nathorst has shown that it is Miocene.

tense coloration. On the pure coal basis, the upper benches contain almost 10 per cent. more volatile than that from the lowest bench.

The Sutarbrandur of Iceland was described briefly by Jardin.¹⁷⁸ Robert had supposed that these deposits consisted merely of drift-wood, but Jardin recognized that the quantity is too great to admit of that explanation. The beds are numerous, having been seen on all coasts except the southern; they are horizontal and their thickness is from mere films to 12 meters. The material is sometimes compact and free from inorganic admixture, at others, it is fragmentary, mingled with pebbles and dirt while at others still it is almost pulverulent. When compact it consists of alternating dull and bright laminae. Mouchet's study with the microscope showed that this coal is derived chiefly from conifers.

Geikie¹⁷⁹ states that in the Faerøe Islands coal of Miocene age is associated with dark carbonaceous clays and is more or less lenticular. The formation is 10 to 15 feet thick on the island of Suderøe, where he observed two types of coal; one is bright, with glassy fracture, not soiling the fingers and not unlike some of the Scotch parrot coals; the other is dull, lusterless, soils the fingers and shows vegetable structure. These alternate in the seams but the dull slaty coal is more abundant than the other. Johnstrup, cited by Geikie, held that every lens of glance represents a flattened stem, in which annual rings can be seen. Geikie found this not true of the thinner streaks and threads. The glance coal has 12 to 14 per cent. of water and only 2.5 per cent. of ash; whereas the better quality of the slaty coal has 11 to 17 per cent. of water and 10 per cent. of ash. The conditions resemble those in the Scottish coal fields, which led Geikie to suggest that the coals are due to gradual accumulation of different plants or of different parts of the same plants.

Fournet¹⁸⁰ saw at Sonnaz near Bourget in France a coal bed with this structure: Lignite, 1.30 m.; clay, 0.30 m.; lignite, 0.10 m.; clay, 0.05 m.; lignite with *Planorbis*, 4 m.

¹⁷⁸ E. Jardin, "Note sur le Sutarbrandur d'Islande," *Bull. Soc. Geol. France*, II., Vol. 23, 1866, pp. 456-459.

¹⁷⁹ J. Geikie, "On the Geology of the Faerøe Islands," *Trans. Roy. Soc. Edinb.*, Vol. XXX., 1882, pp. 227-230, 240, 267.

¹⁸⁰ J. Fournet, "Note sur les lignites tertiaires de la Tour-du-Pin (Isère)," *Bull. Soc. Geol. France*, II., Vol. XI., 1854, pp. 763-772.

This bed underlies 52 meters of sand and gravel; at 5 meters below it is a thin streak of lignite resting on white clay, which contains *Helix* and *Planorbis*. At Tour-du-Pin, the partings are marly and the underclay contains laminæ of lignite, which become thicker as the bed is approached. The lignite there is distinctly laminated and is so hard that it can be removed only with picks. The laminæ, completely "bitumenized," show vegetable impressions but no leaves or flattened stems. Near Vion, on the border of Isère, mineral charcoal is abundant between the laminæ and embedded trunks of trees are not rare. Some parts of this deposit are brown, but others are "bitumenized." The constituents are distinct, for Fournet recognized débris of birch, juniper, fir, cherry and walnut, with sedges, rushes, elytra of insects and *Planorbis*. He was impressed by the remarkable resemblance to coal beds; the partings, the passage of the floor into the lignite, the lamination and the abundance of mineral charcoal. One cannot fail to see in Fournet's description an equally close resemblance to peat deposits; land and freshwater mollusks, elytra of insects, all found in the lignite as well as in the underclay, the character of the plants, the structureless mass in which the plant remains and the shells are embedded.

Daubrée¹⁸¹ published some notes respecting his observation in the Lower Rhine area. Near Soultz-sous-Forêts, he found marls with layers of sand. The latter contain bituminous lenses, which near Bechelbronn have 2 per cent. of bitumen with some pyrite. They hold much carburetted hydrogen and disastrous explosions have occurred in the works. Some thin beds of lignite were seen, which have impressions of *Helix*, *Lymnæa* and *Bulimus*. The same shells were seen at Lobsann, where, above the marls, are freshwater limestones with thin lignites, in all from 5 to 9 meters thick. This limestone yields 10 to 18 per cent. of bitumen and contains gypsum as well as pyrite. It is rich in *Chara*, the individuals being silicified and remarkably well preserved; but other remains of vegetables are in poor condition.

The lignite streaks are very thin and only some millimeters apart, there being alternate layers of lignite and limestone, sometimes 40

¹⁸¹ Daubrée, "Notes sur le gisement du bitume, du lignite et du sel," etc., *Bull. Soc. Geol. France*, II., Vol. VII., 1850, pp. 444-450.

to the meter; but occasionally the lignite is 30 to 60 centimeters thick and is mined. Quartz masses are present in the lignite as well as in the limestone, which, judging from Daubrée's description, are probably of secondary origin. This Lobsann fuel is the lignite bacillaire, the Nadelkohle, which is merely débris of palm trees, from which connective tissue has been removed, leaving the loosened bundles of fibers. This constitutes the greater part of the beds and the arrangement shows that the stems were prostrate. But with this is another fibrous type, much finer and allied to mineral charcoal. Microscopic examination proved that this is derived from coniferous wood; palms and conifers were associated in the forests. Succinite is abundant in this lignite, but the balls are rarely larger than a pea and usually are of pinhead size; he counted 40 droplets in a cubic decimeter. It is most common in beds consisting largely of coniferous débris, the fibers of mineral charcoal being still impregnated with the resin, as appears distinctly under the microscope. This lignite is always laminated, the laminæ being less than one millimeter thick and alternately bright and dull, the latter being the less pure. *Bulimus* and *Planorbis* were obtained from the lignite. This freshwater series of lignites and limestones is succeeded by marine marls, containing *Spatangus*, *Cerithium*, *Venericardia* and other forms of similar habit.

Potonié¹⁸² described the great deposit of brown coal near Senftenberg in Niederlausitz. The bed is more than 10 meters thick, and is mined by stripping at several places. The author gives reproductions of two photographs, one being a panorama of the principal excavation, the other showing distribution of erect stumps. As in many recent and Quaternary peat deposits, one finds here several generations of forest, one above the other, embedded in humus material, the only difference being that homogeneous peat has been converted into brown coal. In the floor, as in the roof, are many great erect stumps, those of the former being rooted in the underclay, those of the latter, in the brown coal. Some stumps have a diameter of several meters and the intervals between trees are such

¹⁸² H. Potonié, "Ueber Autochthonie von Carbonkohlen-Flötzen und des Senftenberger Braunkohlen-Flötzes," *Jahrb. d. k. preuss. geol. Landesanst. f. 1895*, p. 97 ff. Citations from separate, pp. 19-24.

as are observed in recent forests. These belong mostly to *Taxodium distichum*, the bald cypress of American swamps. Many of the stems are hollow and, especially those near the bottom of the mass, contain Schwelkohle. The presence of an ancient Torfmoor, resting on the clay cover of the brown coal, indicates that peat-making conditions recurred here until diluvial accumulations began. The sand overlying this old bog contains erect stems belonging to either *Pinus sylvestris* or *Picea excelsis* and stumps have been found in the peat itself. One great uncompressed fragment of a trunk was found by Potonié, but usually the prostrate stems are flattened. The presence of Schwelkohle in the hollow stumps led the author to suggest that it was formed by the flow of resins, which, he thinks, must have been great in the injured trees. Schwelkohle is, for him, essentially a fossil resin; it burns with brilliant flame when pure.

The forest of the roof is well shown in a photograph reproduced on a postal card, for which the writer is indebted to W. Gothan of Berlin. It shows ten or more erect stumps, 4 and more feet high, distinctly rooted in the coal and associated with some prostrate stems. These were overwhelmed by the detritus which brought peat-growth to an end. Kukuk^{182a} has reproduced a noteworthy photograph of the Victoria stripping in Niederlausitz. The brown coal has been removed and the floor is exposed with the very numerous great rooted stumps of *Taxodium distichum*.

Russwurm¹⁸³ has given a section of the brown coal bed at Orebkau, about 50 miles south-southwest from Frankfurt a.O. and somewhat more than 10 miles northeast from Senftenberg. The bed is 9 meters thick, is divided by a thin parting and underlies 10 meters of mostly black clay, containing comminuted fragments of plants. The upper bench, free from wood, is lump coal (Knorpelkohle) and bears shipping, so that briquetting is unnecessary; but the lower bench is fine coal (Formkohle) and tender, but it is rich in wood, the quantity increasing downward until at the bottom the stems predominate. Russwurm found no erect stems. A second bed, at times 3 meters thick, is here at half a meter to 4 meters below the main

^{182a} P. Kukuk, "Unsere Kohlen," Leipzig, 1913, p. 25.

¹⁸³ P. Russwurm, "Braunkohlen Formation, etc., bei Orebkau," *Zeitsch. f. pr. Geol.*, Jahrg. 17, 1909, pp. 87 ff.

bed; at one excavation, the beds are so near together that they are mined as one, but elsewhere they must be mined separately.

According to Katzer, the Bohemian brown coals belong to the Miocene. Grand'Eury¹⁸⁴ says that at Steinkirche near Budweis in southern Bohemia, the mass of lignite, at the bottom of a superficial basin, filled with sand, lignitic clay, wood, herbaceous plants and roots, is a forest peat covered with mud. Katzer¹⁸⁵ reports that in the Budweis area he saw a coal bed, consisting of an upper bench, 3 decimeters thick, with stems almost completely coaled, and a lower bench consisting mostly of Moor- and Erdkohle. At another place, a bed, 2 meters thick, holds here and there, a great abundance of stems and is so pyritous that it is utilized in the manufacture of vitriol. The same author¹⁸⁶ has described the Grottau beds on the Neisse River, immediately south from the border of Saxony, which are in the middle or lower Miocene. In one shaft, 45 meters deep, 47 layers of alternating coal and shale were crossed. The important bed, reached at 4 meters from the surface, has four benches of coal, in all 10.35 meters, separated by three thin partings of clay and shale. Another shaft shows similar alternations but the succession differs somewhat, the second and third partings being irregular, sometimes absent. The principal bed has an extreme thickness locally of 16 meters in the western part of the trough, where dips rarely exceed 5 degrees and the beds show little evidence of disturbance, aside from crevices in the coal. The eastern wing of the trough is much disturbed, faults and folds occur frequently while the crevices in the coal, often still open and half a meter wide, extend downward 5 or 6 meters. Sulphates, chiefly alum, are shown on the walls of these crevices.

The Grottau brown coal consists very largely of "fossilized wood." Freshly removed from the mine, it has a wood-earthy appearance; but when dried the blocks not only preserve the wood structure but show also the forms of stems, roots and branches, all

¹⁸⁴ C. Grand'Eury, "Sur la formation des couches de Stipite," etc., *Comptes Rendus*, T. 130, 1900, p. 1688.

¹⁸⁵ F. Katzer, "Geologie von Böhmen," Prag, 2te Aufl., 1892, p. 1425.

¹⁸⁶ F. Katzer, *Oesterr. Zeitsch. f. Berg. und Hütt.*, Bd. XLV., 1897. Separate, pp. 5-18.

pressed flat. The color is brown or reddish brown, but usually the bark is black. Stems and coals are not in separate layers but are intermingled. At times the coal is very impure and spaces between the stems are filled with loamy mud. Occasionally one finds nests of soft, deep black, sometimes granular coal, resembling linden charcoal. The fresh material can be worked with a knife, saw or plane; after complete drying, it can be pulverized only with difficulty. The wood-like coal, dried at 110° C., has carbon, 53.22, hydrogen, 5.56, oxygen and nitrogen, 37.95, ash, 3.27. This is better than the average as generally the ash is higher.

The "gas coal" of Falkenau occurs, according to Katzer, as the top bench of the middle coal bed at that place, and is somewhat more than 30 inches thick. The lower benches of the bed are thin, irregular and of poor quality. Von Gümbel's¹⁸⁷ study of this Falkenau material showed that it consists chiefly of much disintegrated vegetable matter. Treated with Bleichflüssigkeit, it exhibits the needles of intermingled Faserkohle. With these are abundant pollen exines and very many minute bodies resembling those seen in diluvial brown coals. The deep brown spores of lichens or algæ are clearly recognizable. The voluminous mostly white ash, 7.75 per cent., consists of clay flakes and quartz grains with some fragments retaining plant texture. This composition, as ascertained by v. Gümbel, is very much like that of a Lebertorf.

The Lower Miocene deposits of Brennberg near Oedenburg in Hungary were studied by Nendtvich,¹⁸⁸ who described the coal as a lens. It has suffered much from disturbance, the dips varying from 40 to 50 degrees and crevices in the coal are filled with Russkohle (soot-coal) and slate. The thickness in the deeper part of the basin is from 10 to 20 fathoms, but the bed decreases toward the borders. The woody structure is distinct in some portions of the coal, which are finely fibrous and in part like ebony. The faux-toit is well-marked, consisting of alternating layers of coal and clay, and shows leaf impressions. According to Grand'Eury, the underclay contains no roots.

¹⁸⁷ C. W. v. Gümbel, "Beiträge," etc., p. 145.

¹⁸⁸ C. M. Nendtvich, "Ungarns Steinkohlen," etc., *Haidinger's Berichte*, Bd. III., 1848, p. 38.

Hantken¹⁸⁹ summarized the available information respecting the Miocene coals of Hungary. He found that the conditions in the middle Miocene resemble those in the Pliocene, in that the coal deposits occupy very small areas and vary greatly in thickness as well as in quality. A bed near Edeleny, 3.24 meters thick, has four benches; the clay partings are in all less than three fourths of a meter; one is pyritous, another contains *Helix* and plant remains and the third is carbonaceous. The underclay is carbonaceous and contains *Helix* as well as plant impressions. The deposits near Brennberg and Saljo-Tarjan are more important. The coal bearing group, at the bottom of the Miocene, is 27 to 40 meters thick and holds four coal beds at Brennberg, from 2 to 7.5 meters extreme thickness. The overlying sandstones are about 130 meters thick. At Saljo-Tarjan, the main bed is 2 meters thick, underlies sandstone and conglomerate and rests on marly clay. But Grand'Eury found that the floor varies. At an opening in Saljo-Tarjan, the coal rests on rhyolite-tuff, but at Mitra-Novak one coal bed rests on sandstone while another rests on clay.

Katzer¹⁹⁰ has described in considerable detail the brown coal deposit near Banjaluka in Bosnia, which, according to the fauna, appears to be Miocene, though its flora indicates Oligocene age. Tertiary beds occupy a basin of about 80 square kilometers and are surrounded by rocks belonging to different periods. The succession of psammites, marls, limestones and tender conglomerates is apparently freshwater throughout. The one important coal bed, mined near Banjaluka, is in three benches; the partings are very thin in the northwest part of the mine, where the bed is single; but they thicken rapidly, the upper and middle benches disappear in succession and only the lowest or Laüser bed remains. Where the bed is triple as in the Laüser district, the succession is: Hard limestones and soft marls, freshwater, 100 meters; marls, more or less carbonaceous, containing *Melanopsis*; upper bench of coal, with extreme thickness of 4 meters; gray to brown marls, calcareous, containing on top layers of compressed *Unio*; middle bench of coal, 2 meters; yellow to gray soft

¹⁸⁹ M. Hantken, "Die Kohlenflötze und Kohlenbergbau," etc., pp. 313-325.

¹⁹⁰ F. Katzer, "Die Braunkohlen Ablagerung von Banjaluka in Bosnien," *Berg. u. Hütt. Jahrb.*, Bd. LXI., 1913, pp. 153-227.

marls, with many films of bright coal and layers filled with compressed fossils, mostly *Pianorbis* and *Melania*; Lauser coal or bottom bench, 2 to 2.5 meters; gray, brown to blackish sandy marls with thin-bedded calcareous marls holding coal smuts and carbonaceous shale.

In reading this section, one might easily suppose that it refers to some peat locality in northern Ohio. The coal differs somewhat in the several benches but the general character is the same throughout. The woody portions pass gradually into Pechkohle, which is the prevailing type and is not always laminated.

The Oligocene Coals.—In the Zsil Valley of Hungary, according to Hantken,¹⁹¹ the great adit, which crosses 567 meters of Oligocene rock, dipping at 30 degrees, cuts 14 beds of coal, one of which is 41.12 meters thick. The marly beds in contact with the coal are very dark and contain carbonate of iron. At Szt. Ivan in the Gran district, a bed, 12.4 meters thick, has four benches of coal, the partings being freshwater limestone and in all 3.7 meters thick. It underlies a conglomerate of dolomitic fragments and rests on a carbonaceous shale passing downward into freshwater limestone. Partings in coal beds of this Gran area show notable variations in thickness, one of them increasing in a short distance from 1.9 to 17.45 meters. Freshwater conditions seem to have prevailed almost throughout, but in the Nagy-Kovacsier basin, the lowest coal bed underlies shale containing *Natica* and *Cerithium*, though freshwater limestones are the predominating rocks above. The coal shows marked variation in composition. Nendtvich¹⁹² said in 1848 that the coal of the Gran region is black, with dull luster, mostly shaly but sometimes with conchoidal fracture. It is non-caking and yields only a slightly luminous gas. The woody character must be marked, for Nendtvich speaks of the material as tough and hard to pulverize. The chief drawbacks are the readiness with which it falls to pieces on exposure and the tendency to spontaneous combustion.

The Oligocene coals of Germany are found in many small areas. Plettner¹⁹³ described in detail the greater number of the compara-

¹⁹¹ M. Hantken, "Die Kohlenflötze," etc., pp. 247, 259, 260-263, 280, 286, 289.

¹⁹² C. M. Nendtvich, "Ungarns Steinkohlen," etc., pp. 25-31.

¹⁹³ Plettner, "Die Braunkohlen Formation in der Mark Brandenburg," *Zeitsch. d. d. geol. Gesell.*, Bd. IV., 1852, pp. 249-483.

tively small basins within Brandenburg, where the coals are of great importance. At Wittenberg, on the Elbe, where the bed is 8 to 12 feet thick, the coal is blackish-brown and pulverulent; the inhabitants wet it and mould it into bricks. The upper part of the bed contains much fine quartz sand, but there is none in the lower portion. The dips vary from 9 to 20 degrees. A rather extensive basin is near Muskau, on the Neisse River about 70 miles south of east from Wittenberg, where the coal is hard, imperfectly laminated and shows numerous imprints of leaves on surfaces of the laminae. It rests on a fine clay and underlies about 10 feet of sand, succeeded by 5 inches of leaf-bearing clay, above which is another coal bed of unknown thickness. The coal is dull with earthy fracture and shows no trace of organic structure, aside from the leaf imprints. A yellow resin, mealy or dust-like, is abundant. At Grüneberg, 50 miles northeast from Muskau, the coal is hard and laminated; it is dark brown but the included plant remains, heaped in great quantity on the surfaces of laminae, are yellowish brown. The waxy yellow resin is plentiful and is often enclosed in the fossil wood, especially between the annual rings.

Fürstenwalde is near the river Spree at a few miles west from Frankfurt a. O. Plettner has preserved the records of numerous shafts and borings, which exhibit such variations that the coal beds must be lenses. The dips are from 20 to 70 degrees. The important bed is triple. The great bench at the bottom, 10 to 11 feet thick, is the best and usually contains little Formkohle; but, at times, that type of coal forms most of the upper benches. There is a notable difference in quality, coal from the middle bench being the worst. Plettner in this district distinguished three types of coal, which he recognized elsewhere: (1) Knorpelkohle, the hardest and most appreciated, brownish to coal-black, with at times a bluish luster; it breaks into Knorpel or sharp-angled parallelopipedons, 2 to 9 inches in diameter; the fracture is earthy, luster none and plant remains are not common; (2) Erdig- or Formkohle, light brown, of loose texture, earthy, friable. (3) Bitumenöse Holz, which is present in all benches of a bed, embedded in the coal; sometimes it is fragmentary but at others whole stems are found; these are usually prostrate, erect stems being

rare. There is little difference in the wood and the fragments appear in all cases to belong to the genus *Pinus*. Ordinarily they are compressed and the annual rings are ellipsoidal. A yellowish-white resin, without succinic acid, is present in all types of the coal.

Buchow, west from Fürstenwalde, is at a few miles east from Berlin. There the coal is laminated with, as Plettner remarks, enough bitumenöse Holz to keep one from forgetting the vegetable origin of the coal, as he might do if he consider only the homogeneous substance in which the wood is embedded. At Freinwalde, 15 or 20 miles north-northeast from Berlin, the dip is only 10 degrees, whereas at Buchow it is 15 to 60. The coal at Freinwalde contains no wood and burns with a very disagreeable peat-like odor; this type, observed also at Buchow, is the Moorkohle of Plettner. Plant remains, recognizable by the unaided eye, are few, and such as were seen were pierced by threads of resin; but, in the neighboring area of Falkenburg, wood abounds.

This Moorkohle is shown near Frankfurt a. O. and at some other places. The dips in the basins of this eastern region vary from 10 to 60 and in one basin even to 90 degrees. At most localities the coal is laminated and contains resin as well as wood; the latter is often converted into Pechkohle and in that conversion it loses structure. Plettner calls attention to the fact that the change into Pechkohle rarely affects the whole fragment. The converted portion is not altered by exposure to the air and does not separate into lamellæ.

The coals of Sachsen or Prussian Saxony have been studied by many observers. Laspeyres¹⁹⁴ examined an area near Trotha and Dolau, where the coal was mined by stripping. The lower bed is 2 to 6 meters thick and divided by an irregular parting of sandy clay. The upper bench is often so poor as to be worthless; the lower bench is better but consists chiefly of Formkohle with some Knorpelkohle. It contains much coarse or earthy retinite in nests, streaks or layers, as well as much pyrite, petrified wood and charcoal. At a little distance higher is the upper bed, with extreme thickness of 5 meters. This consists of Formkohle, small particles of brown-black coal, more or less closely packed together. Occasionally it is dust-

¹⁹⁴ H. Laspeyres, "Geognostische Mittheilungen aus der Provinz Sachsen," *Zeitsch. d. d. geol. Gesell.*, Bd. XXXIV., 1872, pp. 298-302.

like and of cinnamon color, a Schwelkohle. Some Knorpelkohle is present along with bituminöse and petrified wood, the replacement in the latter being with pyrite or silica. The plant remains are chiefly wood, which predominates in some parts. This is wholly coniferous and, excepting a few Abietinae, belongs to cypress. Occasionally one finds great stems passing gradually into either earthy or compact coal, in which Laspeyres thinks he has proof that the varied conditions observed in coal must be ascribed to irregular working of the conversion process, though he is convinced that much of the earthy brown coal may be due to destruction of other parts of the plants, which, being tender, offered less resistance to the process and lost all structure.

Credner,¹⁹⁵ in discussing the same area, gives as the Oligocene succession: Lower, consisting of light-colored sands, clays with brown coals; Middle, dark gray to green gray sands and clays with marine forms; Upper, light-colored sands, gravels, clays with brown coals.

The Lower Oligocene, about 100 meters thick, is a mass of irregular variable strata. The coal beds are usually 4 to 5 meters thick but in places a maximum of 8 or 9 meters is reached. There seem to be practically two beds, but his general statement exhibits the irregularity of deposit, for he says, (1) That the beds are not continuous, but are interrupted locally, as they thin out; (2) Consequently only one bed occurs in places where two were expected; (3) It is questionable if these apparently local, lens-like individual beds are actually one and the same throughout, for the relations of the beds are extremely variable; (4) Locally, one finds more than two beds.

The coal is mostly earthy or soft brown coal, mingled with more or less of Knorpelkohle and bitumenöse Holz, the latter sometimes though not often replaced with pyrite and silica. The woody material is in small proportion and all the phenomena indicate swamp origin. In this connection he cites A. Penck's investigation of the Tanndorf brown coal, which showed that the lower shaly portion of the deposit is rich in well-preserved remains of floating plants,

¹⁹⁵ H. Credner, "Das Oligocän des Leipziger Kreises," *Zeitsch. d. d. geol. Gesell.*, Bd. XXX., 1878, pp. 615.

such as *Salvinia* and *Trapa*; the next layer is full of *Arundo* stems with leaves of *Salix*, evidently blown by the wind. Above this is the coal, composed of *Sequoia*, *Betula* and *Palmacites* stems. One sees here the gradual filling of a freshwater basin, through accumulation of *in situ* vegetation. The abundance of still erect tree stems, some rooted in the floor and others rooted in the coal itself and extending meters into the overlying sand, suggest that all the stems, prostrate as well as erect, are those of an *in situ* vegetation.

Naumann¹⁹⁶ remarks that stems, prostrate, piled irregularly and compressed, are often enclosed in earthy brown coal. At times, however, erect trees are found, cylindrical and retaining their roots, so that they are where they grew. One finds in these areas that locally all the prostrate stems lie in the same direction, showing that the same force had broken them off and laid them down. He adds a new example of erect trees. Some years prior to publication of his work, the brown coal had been exposed by stripping near Würzen in the province of Sachsen; on the surface of the coal, within a space of about half an acre, he saw between 40 and 50 trees, their roots interlocked within the coal bed.

A mineral, termed pyropissite, occurs at numerous places within Sachsen, sometimes pure but often mingled with ordinary brown coal to form the Schwelkohle, which has been of no little importance as a source of oils. Stohr's¹⁹⁷ description of conditions, prefacing his discussion of pyropissite, gives some details not recorded by the authors already cited. The strata generally are in no regular order and appear to dovetail; the brown coal alone appears to be well-defined. The formation is from 30 to 60 meters thick and underlies 3 to 30 meters of diluvial deposits. The roof of the coal is sand, clay or hard sandstone and there is a similar variation in the floor, though commonly that is plastic clay. The brown coal, where mined, averages about 6 meters, but the thickness varies from a few centimeters to 10, 16 and at one place 20 meters. Owing to irregularity in the floor, due to prior erosion, the coal occurs in shallow

¹⁹⁶ C. T. Naumann, "Lehrbuch der Geognosie," 2te Aufl., 1862, Bd. III, p. 204.

¹⁹⁷ E. Stohr, "Das Pyropissit Vorkommen in den Braunkohle bei Weissenfels und Zeitz," *Neues Jahrbuch*, Jahrg. 1867, pp. 407-409.

troughs but sometimes it crosses the separating ridge. Not unfrequently, there are "Sandsäcke," where the roof descends, at times, even to the floor. Usually these are filled with sand or gravel but sometimes with plastic clay. The coal is really in one bed, divided in some places by a sandy parting. The lower portion is Knorpelkohle, but is inferior as it contains much pyrite. The upper bench, though Formkohle, is a good fuel. Occasionally, a worthless, heavy, sand-like dust, termed Russkohle, composes whole layers in the bed. Pyrite, gypsum and retinite accompany the coal; at one place, amber, in lumps as large as one's fist, is found in the roof. Bituminous wood, pressed flat, as well as silicified wood is found in many mines.

Fiebelkorn¹⁹⁸ at a later date described the area examined by Stohr. Like him, he recognized only one bed, which where mined is from 4 to 21 meters thick and occupies a rather regular trough. Occasionally another bed, about one meter thick, is seen above it, the interval being filled with clay. The main portion of the trough is divided into numerous subordinate troughs separated by low ridges. Very often the coal is wanting on these ridges and the coal in the troughs is lens-like. The coal is usually earthy in type, a more or less friable mass of yellowish or reddish to dark brown or black material, coarse-grained, with rather shining streak and in general showing no organic texture. Toward the bottom, it not rarely becomes Knorpelkohle; but for the most part it is Formkohle and on drying falls into dust. The bed contains numerous coaled stems separated by spaces of one to five meters. The overlying beds are a succession of white and dark sands with some clay layers, all well exposed at several places where the cover is stripped. The floor is usually clay but sometimes sand. It is well shown near Teuchern and near Granschütz, where roots descending into it from the coal are distinct. He traced these in some cases to the depth of a half meter. They are those of reeds, grasses and rushes, marking the floor of a swamp.

Potonié regarded the Formkohle as, in most cases, of secondary-allochthonous origin. It was originally an autochthonous coal but had been removed and redeposited elsewhere. To this matter, refer-

¹⁹⁸ M. Fiebelkorn, "Die Braunkohlenablagerungen zwischen Weissenfels und Zeitz," *Zeitsch. f. pr. Geologie*, Jahrg. 1895, pp. 353-364, 396-415.

ence will be made in another connection. Raeffler,¹⁹⁹ opposing the doctrine, examined closely most of the mines in the Sachsen area. Extended reference to this work will be made in discussion of the doctrine of Potonié. The plates illustrate well the lens-like form of the brown coals, showing isolation of the several portions of the beds and suggesting that the lenses were not wholly contemporaneous. The rudely crescent forms observed in cross-sections of the lenses with depressed upper surface make clear the effect of compression on the thick mass of vegetable matter midway in the little trough. Several of his profiles indicate "Sandsäcke" filled with "glazial Diluvium." The coal is very little disturbed in many places but in others the plications are very close. Some of these are evidently pre-glacial and the erosion was extreme; but it does not seem to have been contemporaneous in any case.

Pyropissite occurs in some portions of the Sachsen area. It is described by Zincken as amorphous, earthy, with earthy fracture; it is gray to yellowish to white, greasy to gummy feel and fuses to an asphaltic mass; it passes into Schwelkohle, a mixture of pyropissite and ordinary brown coal. Here only the geological relations may be considered; other matters belong under chemistry as of the brown coals.

Stohr,²⁰⁰ in the memoir already cited, states that in southern Sachsen pyropissite is an integral part of the coal bed. The pure mineral yields 40 to 50 pounds of tar to the ton, from which paraffin and mineral oil are obtained; the ordinary material yields only 20 to 25 pounds. Until recently, the Schwelkohle was thought to be worthless and of rare occurrence; but, though absent from most of the area, it is present at many localities. It is not always a distinct bench, but at times forms laminæ in the upper part of the Feuer- or fuel coal. The distribution seems to be lens-like, for Stohr refers to nests of Schwelkohle. A variable layer of Russkohle intervenes between the Schwelkohle and the roof, ordinarily not more than 6 inches thick, but at one stripping he found this layer from 2 to 3 feet. He summarized his observations thus:

¹⁹⁹ F. Raeffler, "Die Entstehung der Braunkohlen lager zwischen Altenburg und Weissenfels," Inauguration Dissertation, Jena, 1911.

²⁰⁰ E. Stohr, *Neues Jahrbuch*, 1867, pp. 410-424.

Pyropissite occurs only where the cover is less than 16 meters; (2) it is sometimes the upper bench, but, where the bed is very thin, it is the only bench; it is not always limited to the upper bench but it may be distributed in the underlying Feuerkohle; it occurs as leaves in the main Feuerkohle, sometimes with distinct demarcation from the surrounding coal but at others passing gradually into it; (3) it is always accompanied by Russkohle, gypsum, and pyrite; retinite appears to be absent; (4) the character of the roof may be important; under gravel and sand it is better than under clayey conglomerate; but under a clay roof he has seen it both good and bad.

Von Gümbel²⁰¹ studied the pyropissite of Weissenfels. It is powdery, dust-like, brown-yellow and difficult to moisten. Under the microscope, it shows only indefinite grains, opaque lumps and scattered leaves, ill-preserved and belonging apparently to some moss. After removing the resinous substances by alcohol and ether and treating the residue with Schultze's reagent, he found little evidence of organic texture, aside from something like Faserkohle; there are some spiral threads, and spores and pollen are indicated by rounded patches. The ash, 14.2 per cent., consists of quartz grains, crystals and opaque black balls. No diatoms were seen. Pyropissite from Sauforst in southern Bavaria and of Miocene age, is in general much the same; but remains of grasses and of moss leaves are numerous, while pieces of wood are present, retaining structure though converted into a yellow friable material like the groundmass. After treatment with ether, the parts of leaves as well as the pollen grains become more distinct; pollen exines are very abundant.

Fiebelkorn, in the memoir already cited, gives sections showing the relations of Schwelkohle to ordinary coal. The bed at Grube 396 near Teuchern is only 6 to 7 meters thick, but at a little distance away it is 16, and, generally speaking, the whole bed is good. Some grains of coal are shown in the roof and the coal itself, especially in the upper part, shows alternating bright and dull laminae. The section at this place is: Black earth, 0.60; loess, 7.50; Tertiary shale and sandstone, 6 to 8; impure coal, 0.30; Feuerkohle, 2.30; Schwelkohle, 0.50; Feuerkohle, 0.30 Schwelkohle, 4; Feuerkohle, 3; clay

²⁰¹ C. W. v. Gümbel, "Beiträge," etc., pp. 146-148.

and roots, 2.50. The measurements are in meters. Fiebelkorn makes no reference to the Russkohle, which Stohr found associated with the Schwelkohle. The distribution of the latter is quite different from that seen by Stohr, for here the two types of coal alternate. The Schwelkohle changes into pyropissite toward the border of the trough.

The Oligocene coal of the Cologne-Bonn region on both sides of the Lower Rhine has been mined during a long period. Davis²⁰² has given a brief description of the deposit near Horrem, which shows the general conditions. The brown coal contains about 60 per cent. of moisture and is soft, at most, slightly consolidated in the bed. Fresh from the mine, it resembles rather woody, half dry peat or muck from a swamp forest. The included wood, mostly lignite, appears, even when dry, to be no more changed or carbonized than the wood found in many peat beds. When dry, it is still soft enough to be whittled easily, the chips being scarcely more brittle than those from kiln-dried wood of similar types. The deposits range from 32 to 328 feet in thickness, the average being about 72 feet. The coal is covered with relatively thin gravel and clay; this overburden is removed by stripping, and the coal is mined in open cuts. The moist brown coal, as it lies in the bed, is nearly black, unconsolidated and contains a large percentage of fine material, which is friable even when wet.

The brown coals near Bonn were studied long ago by Horner,²⁰³ who saw four types at the mines: (1) A dark brown or black earthy substance, friable to pulverulent, rarely showing lamination and found usually as the upper portion of the beds; (2) a cemented mass, in which leaves and fragments of wood are mingled with the earthy coal; (3) wood in different stages of bitumenization, with all shades of color from light brown to black, the last approaching jet; (4) Papierkohle, highly bituminous, burning with bright flame, separating into laminæ as thin as writing paper and leaving a white ash; it is a mixture of earth and comminuted vegetable matter. It should be

²⁰² C. A. Davis, "Production and Uses of Brown Coal in the Vicinity of Cologne, Germany," U. S. Bureau of Mines, Techn. Paper 55, 1913, pp. 5, 6.

²⁰³ L. Horner, "On the Geology of the Environs of Bonn," *Trans. Geol. Soc.*, II., Vol. II., 1836, pp. 449, 450, 459.

noted here that "bitumenization" as used by Horner and others of the earlier writers is practically synonymous with "coalification" of some French writers and refers merely to the extent of conversion.

The several kinds of coal are found at times in a single bed. The wood is ordinarily in fragments of inconsiderable size, but sometimes large stems are found. These, when prostrate, the usual position, are flattened; but trees have been met with, erect, with roots attached and the stems passing through some benches of the coal. Horner thinks that these may have been floated in, being held in position by the weight of the roots. One of these trees was 7 and another 11 feet in diameter; the depth of water in which such trees could be floated must have been considerable. The writer has seen great floods on great rivers and he has seen many floating trees with roots attached, but he has never seen one floating in vertical position, except where it seemed wholly probable that the roots were loaded with earth or stones. If these trees near Bonn had been floated in erect position, the inorganic materials ought to appear with them. Horner states that the wood is often well enough preserved to be utilized in timbering the mines. Pyrite is common and "amber" occurs in irregular balls. The wood, at times, is replaced in part or altogether with carbonate of iron.

The section of a shaft at Utweiler is as follows: Soil, 2 feet 6 inches; loess, 9 feet 5 inches; basalt, 31 feet 9 inches; indurated clay, prismatic, changed by the basalt, 1 foot; clay, coaly, neither slaty nor columnar, 6 inches; black pitch coal, in prisms, perpendicular to face of the basalt and with dolomite in the interstices, 1 foot 2 inches; small coal, 4 feet; brown coal or bituminous wood, unaltered and with structure preserved, contains in the lower portion kidneys of compact clay-ironstone, 8 feet 6 inches.

The influence of the basalt disappears within 7 feet. The constitution of the thick bottom coal recalls the condition so often seen in the lower part of peat deposits formed by encroachment upon forested areas.

Heusler²⁰⁴ has given a full description of conditions in the Lower

²⁰⁴ C. Heusler, "Beschreibung des Bergreviers Bruhl-Unkel und des Niederrheinischen Braunkohlenbeckens," Bonn, 1897, pp. 32-42, 45-52, 132, 161, 163.

Rhine region. The important localities are Deutz, at a short distance west from Cologne, Bruhl and Unkel, about 25 and 45 miles south from Cologne. Other areas are as far as Linz, a few miles beyond Unkel. Three types of coal are found in this region; Blätterkohle or Dysodil, Alum brown coal and the Earthy brown coal which is manufactured into briquets. The first and second, limited chiefly to the upper portions of the basin in the Siebengebirge, extend northward on the left bank of the Rhine to Friesdorf near Bonn, while on the right bank they are found as far as Spick in the Deutz-Runderoth district. Heusler asserts that the difference in these coals has no relation to age and is due merely to local conditions.

Blätterkohle occurs in isolated patches near Linz, Orsburg, Oedingen as well as on the Hardt, especially near Rott. The deposits are irregular and alternate with clay, sand and ordinary brown coal. Near Linz, three layers were seen, 1.1, 0.78 and 4 meters thick, each containing more or less of lignite-like coal and many remains of aquatic animals, 10 species having been recognized. Near Orsburg, three layers were seen, separated by clay and poor coal; batrachians of several genera are abundant in the coal. In an isolated basin, this section was obtained: Hard earthy brown coal with lignite, 0.94; bituminous clay, 0.63 to 1.10; laminated siliceous beds, with leaf impressions, 0.16 to 0.26; Blätterkohle and Polischiefer, 0.26 to 0.78; lignite, pyritous, with leaf impressions and remains of fish, 0.63 to 1.10; semi-opal, 0.16; Blätterkohle, laminated, pyritous, some lignite, nests of Polischiefer, fragments of plants, insects, fish remains, 0.31; gray, pyritous clay, 0.31.

The measurements are in meters. The association with diatomaceous earth is by means unusual. Near Oedenberg, the Blätterkohle is very thick, but is so mixed with infusorial earth as to be of little value. In the Rott area, at the Krautgarten mine, the finely laminated Blätterkohle, at the bottom, is separated by almost 2 meters of grayish-white clay from a meter-thick bed of ordinary brown coal above. In this mine, the coals contain remains of mammals, amphibia, fish, insects of six orders, with crustaceans, mollusks and polyps as well as abundant plant fragments of many types. Heusler's description

shows that here one has a good example of pond-filling. The same relations are seen on the left bank of the Rhine near Oedenberg and Liessen; at the latter, Blätterkohle attains its greatest thickness, varying from 3.8 to 16.5 meters. The total area of rich Blätterkohle barely exceeds one square mile.

Alum brown coal, like Blätterkohle, is confined to the more southerly portions of the region containing the Oligocene basins; it is found especially on the Hardt near Putzchen and Spick on the right, and near Godesberg and Friesdorf on the left side of the Rhine, where it is associated with layers of ordinary and lignite-like brown coal. The Hardt area is about 10 by 4 kilometers and includes the Rott deposit already referred to. The coal there is 3 to 4 meters thick, mostly earthy brown coal and so pyritous that the ashes are used in the alum industry. Midway, is a meter of lignitic brown coal, composed largely of prostrate stems. One of these, a conifer, was 1,600 years old, that being the number of annual rings. But erect stems are by no means rare; one mine near Bleibtreu yielded 35 such stems in a space of 10 acres, the diameter varying from 0.78 to 2.82 meters or about 9 feet. Pyrite replaces or penetrates much of the stems and roots. This lignite on drying becomes black and changes into a typical Pechkohle. The plants are mostly conifers and palms. The relations of the coals are shown in a section measured near Friesdorf, thus: Loam and river drift, 5.2; brown coal and alum clay, 0.94; clay and bituminous wood, 1.26 to 1.57; brown coal (lignite), 0.16; bituminous clay, 0.31; brown coal and lignite, 0.16; gray pyritous clay with lignite, 1.57; brown coal, 2.51; black alum clay, 1.57; Blätterkohle, 0.47; lignite, 0.47; earthy brown coal, 0.94; Blätterkohle, 0.63 to 0.94; earthy brown coal, 0.47; Blätterkohle, 0.63 to 0.94.

The association of Blätterkohle and pyrite seems, from Heusler's sections, to be very intimate at most localities. Nineteen species of plants have been recognized at Friesdorf, a large part of them belonging to genera well represented in swamp floras. Erect stumps are at Füssenich and Stockheim.

Alumkohle and Blätterkohle become rare northward and earthy brown coal, like the Formkohle of Sachsen, is the usual type. Lig-

nite or bituminous wood is present in this coal and the species are like those as on the Hardt and at Friesdorf; stems are especially well preserved in mine Friedrich Wilhelm Maximilian, near Turnich on the Erft, but many of the Hardt species are not represented. Deposits between the Rhine and the Erft are quite regular, with clay floor, containing more or less brown coal, and often have a clay roof, but very frequently the cover is a diluvial deposit of varying thickness, through which water passes into the porous brown coal and downward to the clay floor; this surface water injures the coal. There is no distinction here into earthy brown coal and Schwelkohle as in Sachsen; the only difference is in state of preservation—earthy and lignite-like brown coal. The former is from the soft parts of plants and is utilized in manufacture of briquets; the latter yields the lump coal. It is not known whether or not any Schwelkohle like that of Sachsen exists in this region. The Schmierkohle, found in the Hangerden near Bruhl, is said to yield a greater proportion of distillation products than does the underlying earthy coal; but it is much mixed with clay and has a great percentage of water; both water and ash decrease downward in the mass of the bed. The thickness in the area of earthy brown coal varies greatly and abruptly; in the Bruhl-Liplar region it is from 5 to 104 meters.

The Rhenish brown coal contains in many places what is known as oölite wood, the woody matter being largely or wholly replaced with spherules of carbonate of iron. In searching the survey coal collections at Berlin, Gothan²⁰⁵ found a piece of the brown coal from the Donatus mine near Cologne, which contained similar spherules of carbonate of iron. Deposition had not been confined to the wood, but had reached into the actual peat. Specimens were obtained from Flügel, who had mapped the area, and they proved to be a part of the bed replaced with material like that of the plant-balls described by Stur. Gothan suggested the name of Torfdolomite. Microscopic examination by Hörich showed that the plant remains as a rule are not well preserved; they are so disintegrated that in many cases they cannot be identified. Roots are best preserved, probably because they

²⁰⁵ W. Gothan und O. Hörich, "Ueber Analoga der Torfdolomite (Coal Balls) des Carbons in der rheinische Braunkohle," *Jahrb. k. preuss. Landesanst.*, Bd. XXXI., Teil II., 1910, pp. 38-44.

entered when the surrounding mass had already become peat. They show no sign of compression. Some fragments of stems show the great lacunæ characteristic of plants belonging to a moist habitat. The great variety in the plants suggests that the deposit is a typical Waldtorf, which accords with the belief that the brown coals were deposited as Waldmoors.

Von Gümbel²⁰⁶ examined the Blätterkohle obtained near Bonn. After treatment with Schultze's reagent, it showed under the microscope only scattered plant cells, exines of pollen, algæ-like clumps and some very indefinite particles, which appear to correspond to bits of animal matter. The descriptions by Horner, v. Gümbel and Heusler show that Blätterkohle is of sapropelic origin and that it is wholly similar to Lebertorf.

De Serres²⁰⁷ described Oligocene brown coals in southern France. At the important gypsum quarries of Lac, near Narbonne, he observed that between the beds of gypsum there are others, marly and containing remains of plants and fishes, the latter being freshwater forms. Dysodil, like that of Sicily, occurs in layers between thick beds of marl overlying the gypsum. It is typical, in paper-thin laminæ and burns quickly with an abominable odor. Between the laminæ are enclosed imprints of fishes and plants, the latter apparently dicotyledonous. The number of fishes is prodigious; there are not merely imprints, there is even the actual substance, at times, in the marl beds and between the dysodil laminæ. The lower part of the section is mostly a limestone mass with lignites (brown coal). The succession near Caunnette is: (1) Calcareous sandstone, belonging to the compact gray macignos, exploited at Carcassone, 40 to 50 meters; (2) freshwater limestone, fissile, whitish, without trace of organisms; (3) limestone, very compact, with many fluviatile shells, *Lymnæa* and *Planorbis* being most abundant, 10 to 20 meters; (4) argillaceous limestone, allied to the macignos, 2 to 4 meters; (5) very bituminous freshwater limestone, divided by thin layers of hard, black, lustrous lignite, 10 to 12 meters; (6) carbonaceous shale, blackish, "nerf" of the workmen, contains numerous

²⁰⁶ C. W. v. Gümbel, "Beiträge," etc., pp. 146-148.

²⁰⁷ M. de Serres, "Observations géologiques sur le Département de l'Aude," *Soc. des Sci. Lille*, 1835, pp. 439-471.

Lymnæa and *Planorbis*; (7) first lignite, friable and of inferior quality, often has *Lymnæa* and *Planorbis* in top portion, 0.50 to 1 meter; (8) blackish carbonaceous shale, with river shells and kidneys of freshwater limestone; (9) second lignite, better than the first, but more irregular, 0 to 0.50 meter; (10) blackish carbonaceous shale with freshwater limestone, holding *Unio*, *Lymnæa* and *Planorbis*; (11) freshwater limestone, with more or less of lignite, 10 to 15 meters; (12) third lignite, very irregular, rarely thick enough to be mined; (13) irregular freshwater limestone resting on the nummulitic limestone.

Unio and *Cyclas* occur, though somewhat rarely, in the Caunnette lignite. Near the village of Songragnes, de Serres found lignites of apparently the same age, associated with blackish, bituminous marls, which contain much pyrite and some jet. The lignite encloses many nodules of amber, at times as large as a hen's egg. Some are translucent, others opaque, but all yield succinic acid. The noteworthy feature is the mass of freshwater limestone, with minimum thickness of 250 feet and interrupted only by freshwater carbonaceous shale with lenses of brown coal.

The Eocene Coals.—Molengraaff²⁰⁸ has shown that coal-forming conditions existed in central Borneo during the Eocene. The coal is thin at most localities but occasionally it is of workable thickness. One exposure on the Mandai River has a bed, one meter thick, enclosed in shale and rich in carbonized tree trunks, which are partly silicified. Clayey layers of an overlying sandstone contain many impressions of leaves. On the Taboeng River, he saw a bed in three benches, 4, 1.40 and 2 meters respectively, separated by thin partings of shale and clayey sandstone, in which are concretions with plant imprints. The lower benches are fissile and evidently of poor quality, but the top bench consists of black pitch-coal, which seems to be good. These localities are within one third of a degree north and south from the equator. The sandstones of this coal-bearing group, not more than 40 meters thick, have grains of coal at many places and the associated volcanic tuffs, of undetermined age,

²⁰⁸ G. A. F. Molengraaff, "Geological Explorations in Central Borneo," 1902, pp. 59, 60, 93.

contain erect and prostrate stems, which, according to Molengraaff, are distinctly *in loco natalis*.

Hutton²⁰⁹ described important deposits of brown coal in New Zealand, which belong to the Upper Eocene. At one locality he saw two beds, 6 and 2 feet, underlying and overlying shales with leaves; the dip is 25 degrees. In another valley, the upper bed is 10 feet thick and has dip of 10 degrees. The mining operations are extensive and the coal everywhere is rich in "ambrite." In a later publication, he refers to bituminous shale near Dunedin and to a similar shale near Orepuke. That near Dunedin varies in thickness from 6 feet to 18 inches within a distance of 20 chains—a pronounced lens. It yields 42 gallons of crude oil per ton. The Orepuke shale is equally rich.

The coal of Häring, in the Tyrol, and its peculiarities have attracted notice from numerous students. Reuss²¹⁰ stated that the coal rests on gray to brown shale-clay, which becomes increasingly coal-like as it approaches the coal; at the same time it becomes more calcareous and finally passes into a crumbling coal, mixed with marl. It is rich in shells, *Helix*, *Planorbis* and a small bivalve, usually so crushed as to be unidentifiable. Some layers seem to be composed wholly of these shells; no remains of plants were observed. The coal, at times 30 feet thick, varies from Pechkohle to shining black "Schieferkohle" and nowhere shows any woody structure. The benches are 3 to 6 inches thick and the partings often consist of bituminous limestone, with nests of more or less shell-bearing limestone. The dip is from 30 to 35 degrees. The roof is a thin-bedded fetid limestone with many indistinct bivalves and, more rarely, *Fusus* and *Rostellaria*. It contains also abundant fragmentary remains of plants, among which *Salix*, *Erica*, palms and other forms have been identified.

Von Gümbel²¹¹ speaks of this coal as embedded in undoubted marine marl deposits, containing both brackish water and freshwater

²⁰⁹ F. W. Hutton, Reps. New Zealand Geol. Survey for 1871-72, pp. 107, 108, 181; "Geology of Otago," p. 110.

²¹⁰ Reuss, "Geognostische Beobachtungen durch Tyrol," *Neues Jahrbuch*, 1840, pp. 162-164.

²¹¹ C. W. v. Gümbel, "Beiträge," etc., pp. 149, 150.

as well as land shells, along with remains of plants. The peculiar features of the deposit led him to recognize a condition analogous to that of cedar swamps on the low border of a bay. Treated with Schultze's reagent, the coal shows under the microscope that the bright layers are composed of leaves, epidermis and plant-parts with parenchymatous structure. The dull layers are more intricate. Faserkohle is quite abundant.

Haidinger,²¹² 20 years earlier, had described a characteristic fragment of mineral charcoal obtained at Haring. He thought it probably an inclusion in the peat from which the brown coal was formed. This Faserkohle passes so gradually into the enclosing glance coal that Haidinger was inclined to believe it a case of external conversion into coal. At the same time, the Faserkohle is interwoven with vein-like lines of bright coal, which in his opinion could have been introduced only in a gelatinous condition like that of dopplerite.

Heer²¹³ notes that, near the Dürnten Schieferkohle area, a deposit of lignite occurs in soft sandstone of the Molasse. It often contains tree trunks but other parts of plants have become indistinguishable. Yet one finds marsh plants in the marls overlying the lignite, while the underlying limestone contains *Unio* and *Planorbis*.

The Bovey Tracey deposits in Devonshire, England, were described in great detail by Pengelly.²¹⁴ They had been subject of discussion during many years and the associated clays had been utilized on an extensive scale. The excavation, at the time of Pengelly's examination, was more than 100 feet deep, 350 feet wide and almost 1,000 feet long. His section, greatly condensed, is: Clays, sandy clays, thin sands and 4 beds of lignite, 7 to 15 inches thick; this lignite is poor, loose, brittle, woody; the clays are dark to gray, with streaks and fragments of lignite, 37 feet 7 inches; lignite with partings, 14 feet of lignite in 5 benches with about 7 feet of clay in the partings; the uppermost bench is more or less wood-like and at the bottom is a mass of dicotyledonous leaves; two of the clay part-

²¹² W. Haidinger, *Verhandl. k. k. Geol. Reichsanst.*, Bd. XIV., 1864, p. 241.

²¹³ O. Heer, "The Primæval World of Switzerland," Eng. Trans., London, 1876, Vol. I., p. 32.

²¹⁴ W. Pengelly, "Lignite and Clays of Bovey Tracey, Devonshire," *Phil. Trans. Roy. Soc.*, Vol. 152, 1863, pp. 1019-1038.

ings have streaks or fragments of lignite; the thick bottom bench is No. 25 of Pengelly's section, 20 feet 11 inches; clays and sands, stems and leaves are abundant in the upper half and thin streaks of lignite were seen in the lower part, 44 feet 1 inch; lignite with partings, 17 feet of lignite in 9 benches and 3 feet 2 inches of clay in the partings; the lignite benches are 3 inches to 4 feet thick, 20 feet 9 inches.

Roots descend from the lowest bench of the upper lignite into the underclay and the coal of that bench consists very largely of fronds of great ferns associated with leaves of other plants. The lower bed shows noteworthy variation in its benches. The third, descending, is woody and somewhat charred; the fifth and sixth are very hard and compact, not so tough as some of the others. The bottom bench is divided by a thin parting of "charred lignite" into an upper portion, 9 inches thick, which breaks into "irregular glassy pieces," and a lower portion, 3 feet 3 inches, which is hard light brown, less heavy than the ordinary lignite, is brittle woody and looks like ordinary coal. Mineral charcoal is present in all the benches. Of the about 50 species of plants recognized by Heer, *Sequoias* are most abundant and they form the greater part of one bed. Conybeare²¹⁵ has remarked that, in the Bovey Tracey area, one can see "the most decided wood pass into a substance no wise differing from common coal in chemical characters."

The Lower Tertiary coals of the United States of America are of great economic importance. They are of all grades from woody lignite to bituminous, even coking coal, and anthracite; and all are utilized. The basins and the fragments of basins which have escaped erosion are mostly in areas bordering on the Rocky Mountain region; but besides these there is a very extensive area in Texas and petty deposits are found in a few other localities west from the Mississippi Valley.

The deposits carrying brown coal in Texas have been grouped by Dumble²¹⁶ into the Timber Belt, the Yegua and the Fayette, the last

²¹⁵ W. D. Conybeare, "Outlines of Geology of England and Wales," London, 1822, p. 345.

²¹⁶ E. T. Dumble, "Report on the Brown Coal and Lignite Deposits of Texas," Austin, 1892, pp. 125, 135, 151, 165.

being the newest. Coal beds from a few inches to 10 or more feet thick are numerous in the Timber Belt. The enclosing clays, in many cases, are extremely dark and contain much silicified wood as well as lenticular masses of iron carbonate. Silicified wood is abundant in the Yegua.

Penrose,²¹⁷ in a publication of somewhat earlier date, described the lignite as occurring in a broad area, which in some portions extends eastward to within 150 miles from the Gulf coast. He separated the rocks into two divisions of which the upper may be Miocene. The coal beds are often double, as shown by a section in Robertson county, where the benches, 12 and 2 feet thick, are separated by 2 feet of clay. This is the important bed of the lower group and its coal is lignite, black, friable and woody. The upper group, along the Colorado River, has beds one to 10 feet thick, some of which contain masses of wood, including tree trunks partly silicified, partly lignitized. The coals of this upper group are all in lenticular deposits. Texas brown coals hold not only trunks, branches and leaves of trees but also reeds and other forms characteristic of swamp vegetation. In some beds, the coal shows distinct vegetable structure, but generally the mass of the material has been so thoroughly converted that no trace of structure is visible to the unaided eye. Frequently the coal is amorphous and soft, while at others it is hard, black, brilliant, with either cubical or conchoidal fracture—but all possible gradations exist between these extremes. The rocks throughout are undisturbed and coal of both types appears often in a single section. At the San Tomas mines, 25 miles above Laredo on the Rio Grande, a coal bed was seen with this structure: lignite, 2 inches; clay, 4 inches; coal, 1 foot 3 inches; black clay, 2 inches; coal, 1 foot 3 inches. The underlying clay contains just below the coal streaks of lignite—a faux-mur. The coals are massive glossy black and with conchoidal fracture, without trace of vegetable texture; but the thin top bench is a true lignite with the plant texture well-preserved. Kennedy²¹⁸ in the same state found

²¹⁷ R. A. F. Penrose, Jr., "Preliminary Report on the Gulf Tertiary of Texas," First Ann. Rep. Geol. Survey of Texas, 1890, pp. 26, 43, 52, 53, 94, 95.

²¹⁸ W. H. Kennedy, "Harrison County"; J. H. Herndon, "Smith County"; Second Ann. Rep. Geol. Survey, pp. 155, 156, 267.

at one locality, two embedded trunks, 16 and 20 feet long, 18 and 20 inches thick. The shorter stem was silicified throughout but the other was so at only one end, lignitized at the other; the conditions merging imperceptibly. At one place he saw a silicified stump, of which the interior had decayed before, silicification began. Herndon observed that within Smith county the coal beds are lenticular; the coal is brown to black, earthy to hard and frequently contains resin. Phillips and Worrall in 1913 estimated the brown coal area of Texas at not less than 60,000 square miles. The coal in many mines is very tender and the loss in screening even the freshly mined coal is very serious.

D. White²¹⁹ studied two typical localities in the Texas field, whence a lignite, not very wood-like, is obtained. The deposit near Hoyt in Wood county appears to have been made in a bayou or lagoon of irregular form, one half to three quarters of a mile wide, and it thins toward the margins. The floor is buff sandy clay, traversed locally by large roots of land plants, clearly in place. The coal, with maximum thickness of 9 feet, is dark brownish black, fairly well bedded, mostly moderately xyloid but with many lenses of brownish, more massive coal, with conchoidal fracture, waxy to satiny look, and amorphous; zones of well-laminated coal were seen. These, darker than the main benches, show cuticles and small woody particles, like much Palæozoic coal. The lenses are more or less canneloid. Amber is present in the upper part of the bed, which is distinctly xyloid; mineral charcoal is not abundant, but there is an inch parting which consists of densely matted fragments of charcoal. There were large trees, one log, partly silicified and somewhat flattened, was more than 70 feet long. The roof varies; at times it is "dirty coal," at others it is a bony coal and occasionally it is a carbonaceous clay, several feet thick.

The deposit near Rockdale was laid down similarly in an estuary or bayou, 10 miles long and one half to one mile wide. Two beds are worked by many owners in this area. The floor of the upper bed is gritty clay overlying sand and well-filled with roots, traversing the old soil in all directions at angles to the bedding; some of these are more than 3 inches thick. The bottom bench of coal con-

²¹⁹ D. White, "Origin of Coal," Bureau of Mines, Bull. 38, 1913, pp. 12-19.

sists of one to 3 inches of "black jack," a stiff, black coaly material with fragments of wood and stems. The coal is clean and solid for 6 feet; above that it is streaked with thin washes of white sand and dirt and irregular lenses of sand which seem to be in ripples. Higher, the sand washes are thicker and at length predominate, with intervening black muds, carrying waterworn vegetable materials. Above this is compact laminated clay, 3 feet thick, with many stems and traces of what appear to be roots. The upper part of the dirty coal, where it begins to be laminated, is rather distinctly marked with roots, branching rather irregularly downward and some of them appear to have extended a long distance into the coal below. Many of these seem to have rotted and the cavities to have been filled with white sand and clay, disfiguring the coal. Amber or fossil resin is abundant in some layers and the coal has joints, 10 to 12 feet apart. The lower bed rests on drab clay, filled with roots in place, which is covered by a thin layer of old humus, followed by more than 6 feet of black, splintery coal with conchoidal fracture, becoming dirty and laminated on top. On this rests light-colored clay with carbonized roots, 10 to 30 inches thick, which is succeeded by 6 to 18 inches of coal. Tree fragments are fairly common in this lower bed. White's description shows that the faux-toit is characteristic at both Hoyt and Rockdale; and that the faux-mur is present throughout at Rockdale.

At Lester, in Ouachita county of Arkansas, the lenses of canneloid coal are such that White regards them as presenting the lignite stage of cannel. The locality is in the Camden coal field, which is a small, irregular and very shallow basin with extreme dimensions of 7 by 15 miles. The rocks are unconsolidated sands and clays with some ferruginous sandstone. There is one workable coal bed, varying from 2 feet 6 inches to 6 feet, owing to the uneven floor. This floor is usually clay and holds no roots, except in one place, where it is sand and shows many roots in place. In one portion of the field, a carbonaceous mud forms the bottom of the bed and contains lignitized stems and twigs with fragments of ferns and dicotyledons. The roof is a light gray plastic clay. The coal or canneloid lignite has the general structure and appearance of a somewhat impure

cannel, is so soft and tough that it can be cut with a knife. It is free from foreign matter except at the bottom; occasionally a thin carbonaceous mud, with slender stems as jet-like fragments covers the coal and a thin xyloid bench was seen midway in the bed. The coal has high volatile, high illuminating power, high heating efficiency and gives copious yield of oil when distilled—the best yields 38 gallons per ton.

Thiessen,²²⁰ in discussing this Lester material, says that it consists of vegetable debris from a herbaceous flora, but contains bits of angiospermous and gymnospermous wood, showing that a wood-flora existed. Everything is so well disintegrated and decomposed that very little is recognizable except the most resistant parts of plants. Exines of spores and pollen grains, resins and an undetermined waxy or resinous substance are conspicuous. The interstices are filled with more finely macerated parts of those constituents. Spores of fungi are present but are not abundant. The spore exines are mostly those of ferns, there being few from lycopods, while the pollen is both angiospermous and gymnospermous. Spores and pollen grains make up about 30 per cent. of the mass and are associated with abundance of cuticles. The resinous bodies are of two kinds, one, the lighter in color, is the more refractive and is paraffin-like in consistency; the other is less abundant and less refractive.

Eocene coals of the Rocky Mountains and adjacent areas are especially important within the states of Utah, Wyoming, Montana and North Dakota, where mining operations have been extensive at many places. The citations which follow are mostly from the more recent publications, as those of earlier date were made when opportunities for observation were not so good and dependence had to be almost wholly on natural exposures.

In one area within Utah, Richardson²²¹ found the coal between beds of freshwater limestone, black bituminous, containing abundantly the crushed shells of *Spharium* and *Physa*. One bed is 36 feet thick, with 4 partings, of which the thickest is but two inches and a half. The rocks are faulted and the dip is from 10 to 15°.

²²⁰ R. Thiessen, "Microscopic Study of Coal," the same, pp. 232-238.

²²¹ G. B. Richardson, "Coal in Sanpete County, Utah," U. S. Geol. Survey, Bull. 285, 1906, pp. 281.

degrees. The coal, as far as proximate analysis shows, is a very fair bituminous coal. The deposit is irregular and, in one direction, thins away within two miles.

Eocene deposits cover a great part of eastern Wyoming. Taff²²² found that, in the Sheridan coal field, the upper member of the Fort Union, about 2,200 feet thick, consists of friable, loosely consolidated sandstones, coal beds and slightly indurated shales, all with gentle dip, seldom exceeding 4 degrees. The coal beds are in three groups; the lower or Tongue River contains ascending the Carney, Monarch, Dietz, No. 3, No. 2 and No. 1, Smith and Roland coal beds, all of which are of workable thickness, the thinnest being 5 and the thickest somewhat more than 30 feet thick. The Intermediate group contains some lens-like coal beds, which at some places are of sufficient thickness for mining. The Ulm group or highest has two beds 16 and 12 feet. Nearly all of the beds are at least double and some of the highest beds are broken by partings. The coal is apparently almost uniform throughout; the weather attacks all alike. The only important distinction is that coal from the Intermediate and the Ulm has somewhat more water and shows the texture or fiber of some plants, whereas that from the Tongue River, though high in water, shows no woody texture to the naked eye. The thicker beds for the most part are without lamination; silicified wood is not rare.

Wegemann²²³ examined an area contiguous to that studied by Taff in northeastern Wyoming and continuous with the extensive fields of eastern Montana and western Dakota. The exposed rocks, about 1,000 feet thick, belong to the upper part of the Intermediate and lower part of the Ulm, as defined by Taff. Wegemann saw many local unconformities and great variations in the rocks. A notable feature is the coarse sandstone filling channels in beds of coal and shale, due clearly to subaërial erosion. The cross-bedded sandstone denoting shallow water, the fine shale, proof of quiet water, the numerous coal beds and the repeated evidence of sub-

²²² J. A. Taff, "The Sheridan Coal Field, Wyoming," U. S. Geol. Survey, Bull. 341, 1909, pp. 127-130, 133, 144-147.

²²³ C. H. Wegemann, "Barber Coal Field, Wyoming," U. S. Geol. Survey, Bull. 531, I, 1913, pp. 11, 12, 19.

aërial erosion are regarded as marking the presence of a great river, meandering over broad flats.

The coal is dull black with vitreous streaks and is brittle; but the woody origin is still distinct and fragments of *Sequoia* are abundant, associated with leaves of dicotyledonous plants. Trunks and stumps, erect or prostrate and partially silicified, embedded in the coal or projecting from the sandstone, are by no means rare. Coal beds are usually less variable than the other members of the section. The Healy coal of the Ulm group has been traced in an area of about 600 square miles, but the name designates a horizon rather than a coal bed. Where it is a single bed, it varies within short distances from a few inches to 18 feet, but often it is represented by a series of beds in a vertical section of 50 feet. This horizon is exceptional in extent, other beds, as a rule, having very limited area. One, 15 feet thick, quickly thins to a few inches and disappears; often a bed thins away and another is seen in the section at a little above or below its place. These are merely overlapping lenticular deposits. Contemporaneous deposits of coal are frequently separated by barren spaces. That these conditions, described in detail by Wegemann, are characteristic throughout Wyoming is evident from the incidental references by other observers.

Eocene deposits cover much of eastern Montana, extending northward across the state from Wyoming into Canada and eastward into North Dakota. The isolated basins of eastern Montana have been studied by several geologists. Woodruff and Woolsey²²⁴ examined fields on the western side of the area, where they observed conditions hardly differing from those seen in Wyoming. Woodruff states that the coal beds with maximum thickness of 5 to 10 feet were evidently formed in basins. Many of them have carbonaceous shale, at times containing streaks of lignite, as floor and roof; at one mine he obtained *Unio* in the roof. Woolsey remarks that the coal beds in his area are very irregular and are lenticular. Resin is especially abundant in the Bull Mountain field, where the beds are

²²⁴ E. G. Woodruff, "The Red Lodge Coal Field, Montana"; L. H. Woolsey, "The Bull Mountain Coal Field," U. S. Geol. Survey, Bull. 341, 1909, pp. 94-97, 103, 104: 62-77.

broken by many partings and the coal, more or less laminated, is jointed.

A small area examined by Rogers²²⁵ is farther northeast; there the more indurated rocks of the lower division show mud cracks, cross-bedding and rippled surfaces. The coal of that division is brittle and fairly compact, though in some cases the woody texture is distinct. The coal of the upper division is mostly lignitic; but this distinction is not absolute, for vitreous coal is found in some of the higher beds and woody lignite is by no means uncommon in the lower division. Throughout, the coal beds are irregular; in all parts of the section, beds thin out and others appear at 8 or 10 feet higher or lower, so that Rogers is compelled to recognize horizons rather than contemporaneous separate deposits.

Farther eastward, beyond the Yellowstone River, one reaches the great lignite area with its numerous independent basins, which were examined by Bowen, Herald, Vance, Stebinger and Beckly.²²⁶ The southern or Baker field shows mostly lignitic coal, woody in structure, brown and tough; the beds are broken by partings of considerable thickness and the benches are seldom of workable thickness. In the Terry field, all the deposits are irregular; the coal beds vary abruptly in thickness and character, often changing from coal to shale within a few yards. Even the comparatively persistent bed at the base is so irregular that Herald is inclined to speak of it as a "lignitic zone." The lens-like form of the deposits is characteristic throughout. The Glendive area is somewhat farther north. The lowest coal bed is apparently continuous along an outcrop of 150 miles, but Hance found it extremely variable in thickness and quality. Its coal is inferior to that of the bed, 50 to 150 feet higher. In places, two sets of joints are distinct.

Stebinger, after study of the Sydney field, which extends to the Canadian border, was not willing to admit that the lens-form is a persistent feature, though he recognizes fully the abrupt and ex-

²²⁵ G. S. Rogers, "The Little Sheep Mountain Coal Field," U. S. Geol. Survey, Bull. 531 F, 1913, pp. 9, 11, 19, 20, 23, 24.

²²⁶ "Lignite in Montana," U. S. Geol. Survey, Bull. 471 D, 1912; C. F. Bowen, pp. 21, 38, 39; F. A. Herald, pp. 56, 60, 62, 78; J. H. Vance, pp. 89, 92, 97, 98; E. Stebinger, pp. 106, 107, 115; A. L. Beckley, 152.

tensive variation in coal beds. Two beds appear to be really persistent for long distances; he had traced for 120 miles one which he regards as the equivalent of a bed in North Dakota. The coal is lignitic throughout, though it often resembles sub-bituminous. After weathering, the grain of the wood disappears, the color changes to black and the material is no longer tough, but is brittle. The greater part was formed from trunks of trees and fragments of wood; even entire logs, usually prostrate, can be traced on the fresh face of a mine. Coal in the lower 500-feet of the formation is less woody in appearance than that from the upper 500 feet. The extreme variability of the coal beds led him to infer that conditions were very unstable in the old moors. Beckly found the lignite very tough and wood-like in the Culberston field.

In considering the remarks on Montana areas, one must bear in mind that in most of the region the studies have been confined to natural outcrops and that tracing of the beds has been made in considerable areas by means of clinker lines, the burned outcrops. Extensive mining operations are concentrated, the localities being very few. The intervals between coal beds are reported as varying greatly. Speaking in a general way, it would seem that the measurements are too few for determining whether or not such variations are merely irregularities. The comparatively few detailed measurements are not enough to show the relations of the several benches of any bed in a large area. There is enough, however, to raise doubt respecting the actual continuity of the beds for any considerable distance.

Leonard,²²⁷ in his synoptical description of the Dakota region, calls especial attention to the great variability of the accompanying rocks. The coal seams are from one inch to 33 feet thick and usually they are not persistent in extended areas. A seam may be pinched out or perhaps it may be replaced by another at the same or a slightly different horizon. Two seams may overlap, so that while both are to be seen in one section, only one of them may be present at half a mile away. Some can be traced in the river bluffs for

²²⁷ A. G. Leonard, "North Dakota-Montana Lignite Area," U. S. Geol. Survey, Bull. 285, 1906, pp. 316-330; A. G. Leonard and C. D. Smith, "The Sentinel Butte Lignite Field," Bull. 341, Pt. 2, 1907, pp. 15-35.

several miles, but sooner or later they disappear. In Dakota, the coal is largely wood-like, tough and showing the grain; flattened trunks of trees frequently differ little from wood except in color. Often, the same seam is composed of alternating layers of tough, brown lignite and of black, lustrous more brittle material. The character of the coal changes toward the west; in Dakota it is woody and brown, but just beyond the Montana line it is largely lustrous; the same feature was observed still farther west at Glendive.

Leonard and Smith saw 9 coal beds of workable thickness, the lowest of which, according to Beckly, is about 400 feet above the Glendive bed—at the bottom of the Eocene. As result of broader studies, they modify the general assertion of lens-form and assert that some of the important beds have been traced continuously for 24 miles, while they have been correlated with much certainty for greater distances. Dips are very gentle throughout the region examined. Pockets of lustrous, black, textureless and brittle coal are scattered through many seams and are less pure than the lignite.

The Eocene coals continue into Canada, where they become less important and are overshadowed by those of the Mesozoic.

D. White²²⁸ examined several localities within the Dakota region and gathered material, which was studied microscopically by Thiesen. The observations are so important that they must be given in full abstract. The coal bed, mined at Wilton, North Dakota, is near the bottom of the Fort Union or early Eocene, a freshwater formation, which stretches, in almost horizontal condition, from central North Dakota westward to the foot of the Rocky Mountains. At Wilton, the floor of the bed is white plastic clay, 4 to 5 inches thick, resting on white sandy clay and occasionally showing large roots in the place of their growth. The thickness of the coal is said to average about 7 feet, with a maximum of 14. The lowest 18 inches is a good lignite, broken by very thin clay partings; a half inch parting of mineral charcoal appears at several feet higher. A thin bench was seen, consisting of laminated coal, which resembles the bituminous types of Palæozoic and Mesozoic. The top coal includes a bony bench, formed apparently from dead aquatic or far-decayed vegetation mingled with mineral sediments, and a brownish

²²⁸ D. White, "Origin of Coal," pp. 7-11.

layer near the bottom appears to contain grasses, stem fragments and chips of wood. The basal coal is almost black as are also the lenses or local layers of amorphous coal. When freshly mined, the mass is distinctly woody, tough and somewhat elastic; some large pieces are brownish-yellow as if from a recent bog. Often the "brown wood of a single piece verges into black, and even into a typical glossy lignite, having a conchoidal fracture and approaching jet. It is notable that the probable saturation with decomposition products in solution, that has produced the jet-like wood, resembling black vulcanized rubber, has not penetrated to the center of some of the fragments, which are inwardly brown or even yellow." Parts of some fragments appear to be charred while other parts are brown and woody. Wood makes great part of almost all the hard pieces examined, and logs, lying in all directions, are frequently in masses. To the naked eye, resin appears to be present in small quantity; silicified stems rarely occur.

The noteworthy features of the bed at Wilton, as summarized by White, are (1) an underclay, seemingly penetrated by roots; (2) evidence of periods, when herbaceous vegetation held the ground in certain areas and produced thin benches; (3) evidence of periods of great accumulation of wood of arboreal size; (4) relative scarcity of thinly laminated earthy or amorphous lignite (peat), this being dependent on the more or less nearly complete decay of the plant tissues; (5) evidence of frequent near approach to asepticity in the water body, so that decay seems to have been arrested quickly; (6) evidence that the surface was exposed at times to air, leading to formation of mineral charcoal. He thinks that the high water-content is a legacy from an unreduced or immature brown peat and also that the accumulation of logs, decayed only in part, indicates rapid growth of the coal.

The coal at Glendive, Montana, is very near the bottom of the Fort Union; it has been followed in a northerly direction for more than 50 miles. The fuel is dull black lignite, containing a large proportion of wood, sometimes in great slabs, both dull and jetified. No roots were seen in the underclay; mineral charcoal is present in a layer as well as in scattered pieces and the coal contains very many

lumps of amber-like resin, some of them apparently still attached to the wood. At the bottom of the bed there is a thin layer of dirty lignite.

The coal at Lehigh, North Dakota, is in the upper portion of the Fort Union, and the bed mined there is but one of many, 20 seams having been counted in one short section. Most of these had been laid down in freshwater swamps; usually they rest on underclays and frequently they have clay partings. The thickness is reported as varying from 6 to 8 and even more feet, "the greatest developments being found in the hollows of the floor, the coal thinning on all sides to the 'rise,' though on the whole it is relatively regular in bedding and thickness." The bed is singularly clean. The lower bench is free from all partings, except the charcoal layers, which are apt to be sulphurous. It is a dark brown, earth-colored lignite in which the large amount of wood is noteworthy. The grain of the wood is conspicuous as are also compressed trunks of trees with their branches, which compose about 75 per cent. of the whole. Some logs are gnarly, one to two feet wide and several inches thick. Some fragments are fully jetified, others partly so and others still, not at all, aseptic conditions having prevented decay. There seems to be little resin. The roof and floor could not be studied, but roots were observed in underclays of some higher beds.

Thiessen²²⁹ studied the coals of Montana and North Dakota, collected by D. White. They are all xyloid lignites, consisting of 75 to 85 per cent. of woody material. The interstices are filled with débris from a large variety of plants and parts of plants, a binding stuff or "Fundamental matter." This semi-decayed, macerated, disintegrated material, composed of wood, parts of angiospermous and gymnospermous leaves, herbaceous stems, bark, roots, exines of spores, pollen, resinous and waxy bodies, cuticles, is cemented by matter, which apparently was once plastic. Spores and pollen exines form a considerable portion of the mass. The trunks of trees are wholly of conifers, mostly *Taxadineæ* and *Cupressineæ*, with a few *Abietineæ*, there being no stems certainly recognizable as dicotyledonous.

He compares the conditions with those observed by him in peat

²²⁹ R. Thiessen, "Microscopic Study of Coal," pp. 221-232.

deposits within Michigan and Wisconsin, where *Thuja occidentalis* (white cedar), *Larix laricina* (tamarack) and *Picea mariana* (black spruce) abound, the *Thuja* being predominant. The growth is so dense that only a thin mat of mosses, liverworts and lichens with an occasional herbaceous plant can grow on the ground beneath. The peat, on which the forest stands, consists of logs and branches, lying in all directions, much changed and more or less macerated. The interstices are filled with "débris, in which macerated parts of stems and branches, cone scales, leaves, thalli of mosses and liverworts, pollen grains, etc., are plainly recognizable.

Nothing of algal origin was found in these coals.

The important coals of Eocene age on the Pacific coast are those in the state of Washington, where one finds all types of coal from peat-like lignite to hard dry anthracite, passing into graphite. Much of the area was studied years ago by B. Willis and G. O. Smith; but since their examination, mining operations have been developed on a large scale at many places, so that it seems best to utilize in this synopsis only the latest results.²³⁰

The Cowlitz River, rising in southern Lewis county, flows across Cowlitz county to the Columbia. The coal in this area is lignite throughout except where changed by eruptive rocks. At one locality, Collier saw a bed, more than 20 feet thick, as exposed in two open cuts, and composed of material "apparently little better than peat." It contains fragments of wood, which, though brittle, are flexible and elastic. Similar coal was seen in Lewis county, six miles away toward the northwest. The wood is so well preserved that one can whittle it easily. This fuel has little ash and is given to spontaneous combustion. Throughout the area, the coal is so woody that mining is difficult.

Some anthracite has been found on the eastern side of Lewis county, but most of the coal in that area is semi-anthracite to semi-bituminous: the beds are thin and the ash is high. At about 30 miles

²³⁰ E. E. Smith, "Coals of the State of Washington," U. S. Geol. Survey, Bull. 274, 1911, pp. 152, 158, 161, 167, 180, 190; G. W. Evans, "Coals of King County, Washington," Washington Geol. Surv., Bull. 3, 1912, pp. 28, 29, 31-33, 59, 65, 116, 152; A. J. Collier, "Coal Resources of Cowlitz River Valley," U. S. Geol. Survey, Bull. 531 L, 1913, pp. 9, 12.

farther west, in the Ladd area, where dips vary from 32 to 40 degrees, the coal varies from anthracite to bituminous, both coking and non-coking; but in the Mendota-Chehalis area, about 30 miles farther west, the coal is sub-bituminous. Some of the beds in this latter area are more than 9 feet thick; the coal is massive, banded and, in some mines, is on the border line between sub-bituminous and lignite. The dips are from 12 to 54 degrees, mostly above 30. At Mendota, where the coal is grayish-black and low grade sub-bituminous, irregular lenses of soft, cannel-like coal are present. When freshly mined, these are black, but they quickly become brown on exposure. They contain so much volatile matter that when ignited by a match they burn like cannel with a long smoky flame.

In the northern part of Pierce county, 30 to 50 miles north from the Ladd area of Lewis, mining operations are extensive. Two beds at Burnett have laminated, good bituminous coking coal, which has been utilized in manufacture of illuminating gas. The dip is 45 degrees. At Pittsburg, two beds with dip of 58 to 60 degrees are mined and yield bituminous but non-coking coal. At Wilkeson, three beds, with dips of 20 to 60 degrees in different parts of the same mines, give a bituminous coking coal, well laminated, with varying ash in the several benches. The jointing is close and there is not much lump coal. At Carbonado, 12 beds have been worked, all of them more or less broken by partings and with dip of from 20 to 60 degrees. The coal is dense and bituminous, comparing very favorably with good bituminous coal from the Coal Measures. The lowest three beds are described as coking. At Montezuma, the coal is coking, semi-bituminous and the dips are 65 to 70 degrees. Resin occurs in low-grade sub-bituminous and to some extent in the higher grades within Lewis, Thurston and King counties.

Evans made detailed study of the coals in King county. Those in the western part have much moisture and are sub-bituminous, but farther east the bituminous type is not uncommon. The newer coals are more nearly lignitic than those from the lower beds. Throughout the whole column of about 8,000 feet, one finds great variation in composition and, far too often, the ash is so abundant as to make the coal worthless commercially. Several beds are quite regular in

occurrence within considerable spaces, but they change so abruptly in thickness, structure and composition that correlation in the different areas is impossible; the associated rocks are equally variable. The floor is usually clay or shale, often carbonaceous, but occasionally it is sandstone. Some parts of the county lost much coal during formation of pre-glacial valleys, now filled with glacial drift; while several coal beds suffered much from contemporaneous erosion and were replaced in considerable areas with sandstone. Evans notes tree trunks extending from the coal into the roof. D. White,²³¹ when at Rentoul in 1908, saw "kettle bottoms," or erect stumps of trees, 6 to 18 inches in diameter, standing directly on the coal, with black shale and coal filling the casts of the decayed boles. The coal is distinctly xyloid and jetified wood is strongly in evidence. Evans found a silicified erect stump showing the annual rings. Thiessen²³² ascertained that the coal collected by D. White contains a great proportion of *débris*, the quantity being almost equal to that of the woody matter. The woody component is coniferous and resinous; the *débris* is very resinous, apparently almost one half of its mass consisting of such material. Exines of spores and pollen are rather abundant but cuticles are rare.

The province of British Columbia, Canada, adjoining the state of Washington at the north, has a number of isolated coal basins, mostly of small extent. The available knowledge respecting the region has been digested by Dowling,²³³ from whose work this synopsis is taken. It seems probable that the deposits are of Oligocene age in many of the places where the coal is economically important. In the Tulameen district, according to C. Camsell, the coal-bearing rocks occupy a basin in the older rocks, with an area of about 5 square miles. The section measured is about 2,500 feet and the middle portion, 460 feet, carrying the coal beds, begins at 600 feet from the bottom. Four beds with, in all, 20 feet of coal have been discovered and prospected. The coal throughout is in alternate bright and dull bands, the latter predominating; but the dull bands

²³¹ D. White, "Origin of Coal," p. 24.

²³² R. Thiessen, "Microscopic Study of Coal," p. 243.

²³³ D. B. Dowling, "Coal Fields of British Columbia," Geol. Surv. of Canada, Mem. 69, 1915, pp. 263 ff., 289 ff., 298 ff., 309, 321.

include many small lenses of bright coal. The dip is from 20 to 70 degrees, usually about 40. The ash, as shown by the analyses, is rather high, the samples being prisms from the whole bed. Some of the coal gives a strong coherent coke. On Hat Creek, G. M. Dawson obtained this section: (1) Grayish and brownish shales and sandy clays, with thin layers of lignite, about 20 feet; (2) lignite with shales, shaly and lenticular layers of silicious limestone, ironstone and shale; the lignite is fairly good, forms about two thirds of the whole and contains much crumbling amber, 26 feet; (3) lignite with little impurity, compact below, softer above, 42 feet, with the bottom not reached.

The lignite of the great mass is without foreign materials aside from irregular masses of calcareous or silicious stumps. Analyses show that the quality is good, there being only 9 per cent. of ash and 8.60 of moisture.

There are several small areas along the upper portion of the Fraser River; the lignite is unimportant but G. M. Dawson has given some notes respecting the rocks. The material of the upper beds is pale greenish and grayish white, very fine-grained and often a fire-clay; at times it is rich in diatoms. The beds are mostly horizontal but occasionally a local disturbance gives a dip of 20 degrees. Impressions of roots and branches are common and two silicified stumps, evidently in place, were seen. The beds turn up around the stumps and thin out toward them. The lignite, at the bottom of the section, is not in well-defined beds but is interstratified throughout with clays and appears to have been deposited as driftwood by somewhat rapidly flowing water; it is not pure enough to be of any value. Small spots and drops of amber are abundant in some layers. Little is known respecting the extent or importance of the other areas. The field geologists of Canada are in full accord with the palæontologists in the belief that these widely separated deposits were laid down in lakes or in estuaries.

The Eocene coals of Alaska have been studied more or less in detail during the last 40 years. Dall's²³⁴ examinations were made in 1875, and the essential portions of his descriptions have been

²³⁴ W. H. Dall, "Report on Coal and Lignite of Alaska," Seventeenth Ann. Rep. U. S. Geol. Survey, Pt. I., 1896, pp. 771-908.

republished in his report upon a reëxamination of the region in 1895. His studies were confined to the southern coast and the adjacent islands. Coal was discovered long ago on Admiralty Island, which is east from Baronoff Island, on which Sitka is situated. The first opening was made on Mitchell Bay and the coal was tested on the U.S.S. Saginaw, but the resin was so abundant as to render it unfit for use. The beds are very thin but, owing to the urgent need for fuel, they were studied carefully. The especial features are the woody structure and the abundance of resin. Kachemak Bay, near the mouth of Cook's Inlet, on the Kenai Peninsula, is 1,200 miles west from Admiralty Island. Furnhjelm, long ago, saw there a bed of coal, 9 to 11 feet thick, underlying clays, pebble rock and sands, and resting on partly bituminous laminated clay shale. It was black, brilliant and contained grains of amber. From the associated rocks he obtained *Unio*, *Amnicola*, *Melania* and elytra of a beetle, along with 44 species of plants, both conifers and dicotyledons. The bed was no longer exposed when Dall visited the locality, but, at Coal Point, he saw a bed 7 feet thick. In 1895, this bed had been opened at the Bradley mine, where it showed leaf-bearing partings and the best coal was at the bottom. Two other beds were examined on this bay, 4 feet 7 inches and 6 feet thick. These are complex. The coal differs in the several beds; that at the Bradley mine is evidently a glance, not soiling the fingers and, on drying, breaking into cubical fragments, whereas that from the Eastland mine is fibrous, dull charcoal black.

At Amalik Harbor, 150 miles farther west, some thin coal beds were seen, as also at Chignak, nearly 300 miles beyond. Amber has been obtained on the shore of Portage Bay southward from Chignak and from several other places in that region, as well as from several of the Aleutian Islands. Many thin beds of lignite were seen on Unga Island. One of these is very complex; the upper portion has half a dozen benches of bright and dull coal, each 4 to 5 inches thick, with thicker partings of carbonaceous shale. The bench is fairly clean and 18 inches thick. Analyses of coal from this bed gave

On the basis of pure coal, the volatile is 49.55 and 81.26 in the two

coals. Both are described as lignite but the composition of the lower bench, dull coal, suggests that it is of Lebertorf origin. Coal from a bed on Kachemak Bay is of the same type, as it has 71.3 per cent. of volatile.

	Water.	Volatile.	Fixed Carbon.	Ash.
Upper part.....	11.26	40.51	41.24	6.99
Lower part.....	10.58	66.21	15.26	7.95

Eldridge,²³⁵ during examination of a district in eastern Alaska, discovered 10 to 15 deposits of low-grade lignite, 6 inches to 6 feet thick. The material resembles a mass of compressed carbonized wood. Stumps, one to two feet in diameter, are common and stand erect. These, by their appearance and by their association with abundance of slivers and other carbonized material, suggest that the coal beds originated in swamp vegetation. Occasionally, the coal shows no woody structure and resembles the higher grades of lignite, which shade off into bituminous coal.

Collier, not long afterwards, examined beds along the upper Yukon River, where the coal is either lignite or lignitic, little disturbed and usually contains amber. He visited a locality in the province of Yukon, Canada, 20 miles from Dawson and 7 from the Klondike, where R. G. McConnell had seen a double bed with 5 to 6 feet of coal, hard, without woody fiber and of practically the same composition in both benches. At 20 miles below Dawson, he saw 3 beds mined, all with one or more partings and all showing abundance of resin. At Washington Creek, 80 miles below the international boundary, he found a bed measuring clean coal, with thin partings, 5 feet 6 inches; dirty coal, 2 feet 6 inches; sandstone, 2 feet; shale, 2 inches; coal, 2 feet. The dip is 45 degrees, but there is neither crushing nor faulting. The coal is black, glossy and has conchoidal fracture, but it often shows woody structure and it contains streaks as well as grains of resin. The coal beds, seen by Col-

²³⁵ G. H. Eldridge, "Reconnaissance of the Sushitna and Adjacent Territory, Alaska," Twentieth Ann. Rep. U. S. Geol. Survey, 1900, Pt. VII., pp. 21-23.

lier²³⁶ at numerous localities farther down the Yukon, show the same general features as those already referred to.

Martin and Katz²³⁷ found in the Matanuska region beds of dark fissile shale with bands of ironstone. The coal beds, in some cases, are thick and commercially good, but in others they consist merely of thin alternating layers of coal and shale, so that, though the coal predominates, the thick mass is worthless. The upper half of the section, about 1,000 feet, is composed chiefly of dark shales with thin beds of sandstone and many thicker beds of carbonaceous shale, which are leaf-bearing and include petty lenses of coal. The authors saw several fossil logs and tree stumps in an exposure, where one of them is 20 feet long and vertical to the bedding. Petrified fragments of wood appear to be not rare.

Henshaw²³⁸ has given a brief note respecting the great bed on Chicago Creek, in Seward Peninsula and almost directly under the Arctic circle. The dip is 18 to 36 degrees and the thickness is 88 feet. The coal is frozen as in Spitzbergen and the modest mining operations are prosecuted during the short summer. The tunnel had been cleaned out only a short time before Henshaw's visit and he was able to make examination of the whole bed. It is an almost continuous mass of coal, broken only by a few layers of bony coal and sandy shale. Atwood²³⁹ notes that in the Cook Inlet area, the coal beds are many, varying from mere films to 20 feet. At a mine near Tyonek, the coal is a tough, woody lignite and contains large trunks of trees, which are only partly converted. The mode of their occurrence suggests to him that they may be logs drifted into a pond or swamp, or that they are a group of fallen forest trees.

Tertiary coals have been observed at many localities in Siberia, but available notes respecting them are few and the age of the coals seems to be somewhat uncertain. The summary description of

²³⁶ A. J. Collier, "The Coal Resources of the Yukon, Alaska," U. S. Geol. Survey, Bull. 218, 1903, pp. 17, 19, 22-26, 30-39.

²³⁷ G. C. Martin and F. J. Katz, "Lower Matanuska Valley," U. S. Geol. Survey, Bull. 500, 1912, pp. 44-48.

²³⁸ F. F. Henshaw, "Mining in the Fairhaven Precinct," U. S. Geol. Survey, Bull. 379, 1909, pp. 362.

²³⁹ W. W. Atwood, "Mineral Resources of Southwestern Alaska," the same, p. 117.

Siberian resources²⁴⁰ states that south-southwest from the Irtych River a thin bed of lignite was seen, which retains the woody texture and contains grains of amber. Lignite-bearing Tertiaries are of notable extent in the Transbaikal region; they are later in origin than the present topography of the country; the rocks show leaf impressions and contain silicified stems of dicotyledonous trees. The lignite beds are 2 to 4 meters thick but are lens-like, thinning away at the borders.

Some Chemical Features of the Tertiary Coals.—The literature dealing with the chemistry of Tertiary coals is voluminous, but comparatively little of it is serviceable for the present study. Analyses, for the most part, are of coal from localities where the fuel values had been proved long before the analyses were made: comparatively few are from deposits which are not important economically. In the United States and Canada, the samples are prisms from the whole face of a bed, only such partings being removed as should be separated from the coal before shipment. Analyses of such samples afford no clue to the varying conditions during accumulation of a bed. It is well understood that a proximate analysis of coal containing a high percentage of water yields at best only tentative results, varying in any case with the temperature employed. Ultimate analyses are, from the geologist's standpoint, little better, since coals of wholly different types may have practically the same ultimate composition, as was shown by Carnot. Coals are apparently mixtures of various hydrocarbons, respecting which very little is known, as only a few of them are acted on by solvents. But one must make use of the material within reach and much can be learned by comparison of analyses made after the same method; the official laboratories in the United States afford abundant material.

In studying the mature deposits of peat, known as Schieferkohle, v. Gümbel discovered a dopplerite-like material, which had saturated the mass and had become insoluble. A similar substance is in brown coal. Glöckner²⁴¹ examined the black lustrous coal, with conchoidal

²⁴⁰ Le Comité Géologique de Russie, "Aperçu des Explorations géologiques et minières le long du Transsibirien," St. Peterbourg, 1900, pp. 42, 68, 87, 123, 153.

²⁴¹ Fr. Glöckner, "Ueber Zittavit, ein epigenetische, dopplerit-ähnliches Braunkohlengestein," *Zeitsch. d. d. geol. Gesell.*, 1911, pp. 418, 419.

fracture, which he saw in the brown coal of Zittau in Saxony. Siebert and Hermance had thought it identical with Pechkohle or Glanzkohle, but Glöckner objects to both terms as not specific, because they have been employed loosely in description of both brown and stone coals. He regards dopplerite as almost equally bad, because there is no agreement respecting it, except as to the fact that it is formed in recent peat moors. He prefers a new name for this tertiary substance, which is distinguished from dopplerite by its brittleness and its hardness, 2.5. Analysis of this zittavite, dried at 105° C., yielded carbon, 61.89, hydrogen, 5.32, oxygen, 30.43, nitrogen, 0.21, ash, 1.95. Comparing these results with those obtained by Demel, Kaufmann and Schrötter for dopplerite, one finds that Glöckner's material is more advanced than that studied by those chemists. They obtained for air-dried, ash-free dopplerite

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Demel.....	56.42	5.80	37.20
Kaufmann.....	55.94	5.20	38.86
Schrötter.....	51.69	5.34	43.03

One can hardly regard zittavite as a good mineral for, like dopplerite, it varies in composition and there would seem to be little reason for giving it a new name, except to distinguish the geological position. Glöckner recognizes similarity in origin, for zittavite is due to humic solutions formed during change of woody material into lignite and earthy brown coal, which circulate through the mass. He cannot believe that it results from action of calcium carbonate, because limy matter is but 0.47 per cent. of the whole. The characteristics suggest very close relationship to the carbohumins of v. Gümbel. D. White has expressed frequently the conviction that the conversion of wood into jet-like lignite is due to saturation by soluble compounds generated during decomposition of vegetable matter.

With comparatively few exceptions, students of the Tertiary coals have noted the presence in greater or less quantity of resins in streaks, nests or isolated globules, especially in coals of lignitic and sub-bituminous types, even occasionally in those closely allied to

the bituminous grade. The scanty notices of Pliocene coals contain few references to resins, the only definite note being that by Hutton respecting New Zealand, in which he states that the coal often contains large lumps of retinite. Thiessen found much resin in the Miocene coal of Monte Diablo of California; Brown and Potonié note the considerable proportion of resins in the coals of Greenland and southern Prussia. The Oligocene coals of Germany and British Columbia are rich in resin and, at times, it is found in cavities within fossil wood. Eocene coals throughout, when they are lignite or sub-bituminous, are notably resinous, material of that type occasionally composes a great part of the mass. The term retinite is employed frequently as a group name, but the resins are many. Amber or Bernstein, the best known popularly, has been reported from numerous places, widely separated. Dall states that it has been obtained at many points in Alaska; Daubrée observed it in the Bas-Rhin province and Potonié says that it is abundant at Senftenberg. But this mineral occurs in commercial quantity chiefly on the Baltic coast of Prussia, where, according to Karsten,²⁴² it is procured by digging and by dredging. In the former process, the recent sands are removed and the underlying clay shales, known as "amber veins," are exposed, in which are nests of brown coal and amber, apparently much compressed. These overlie coarse greenish sand, under which the important deposit is reached. This, with the overlying sand, extends under the sea and is the source of the amber, which is thrown on shore by the waves or is obtained by dredging.

Potonié²⁴³ states that Bernstein occurs over the whole of North Germany, Poland, Russian Baltic provinces and Finland as well as in many other regions; but it is most abundant in Sammland, near Königsberg. There it occurs at three horizons. The original deposit is now below the sea, whence it is washed up by the waves; but these Eocene beds were gashed by glaciers and now the mineral is found also in glacial drift. The Bernstein forest grew on Cretaceous débris. This fossil resin, originally fluid, is an exudation

²⁴² H. Karsten, "Ueber das Vorkommen des Bernsteins an der preussische Küste," *Karsten's Archives*, Vol. 2, 1830, pp. 289, 290.

²⁴³ H. Potonié, "Der baltische Bernsteins," *Natur-Wochensch.*, Bd. VI., 1891, pp. 21-25.

from a conifer, which Conwentz has named *Pinus succinifera*. The resiniferous organs were mostly in the bark and twigs but were abundant even in the wood itself. The conditions in these old forests were very similar to those observed in conifer forests of Bohemia: there could have been hardly any sound trees in the old Bernstein forests; wind, weather, saprophytes and other plant parasites, insects and other animals caused injury and led to flow of the resin. Bernstein is complex, consisting of gedanite, soft, yellow, transparent and fusing at about 180° C.; glissite, brown, opaque; stantie-nite, black, tender, brittle; bechanite, brown, tender, brittle; succinite, transparent, lustrous, yellow, brittle, fusing at 250–300° C.

The resemblance of these resins to some of recent age is very great and the origin is similar. They are exudations from coniferous trees and are resistant to decomposing agents, so that the proportion becomes greater as the process of decomposition advances in the vegetable material. Amber is associated, at times, with fragments of the trees whence it was derived, but in many places, as is the case with the recent kauri and copal, the woody materials have disappeared, leaving the resin free in the sands.

Pyropissite is locally characteristic of Oligocene coals in much of the Sachsen area of southern Prussia, where it, as well as Schwelkohle, a mixture of pyropissite and fuel coal, is distilled for the paraffins; it occurs also in the Miocene and Eocene of other regions. Karsten,²⁴⁴ in a brief communication to the German Geological Society, described it as a peculiar earthy brown coal, which forms the roof of a bed near Weissenfels as well as of one near Helbra, between Mansfeld and Eisleben. It passes gradually into the ordinary brown coal, has gravity of 0.9 and leaves 13.5 per cent. of ash. At from 100° to 125° C., it gives off a heavy white vapor and at red heat the product is an oily liquid. Stirred in an open vessel, the whole mass liquefies and becomes pitch-like; in burning it gives off a disagreeable odor. The composition, ash and water free, is carbon, 68.92, hydrogen, 10.30, oxygen, 20.78, while that of the associated brown coal is carbon, 64.32, hydrogen, 5.63 [oxygen and nitrogen, 30.05]. The last two constituents are not given by Karsten.

²⁴⁴ Karsten, *Zeitsch. d. d. geol. Gesell.*, Bd. II., 1850, p. 71.

Schwelkohle was formerly cast aside as worthless, but it has been utilized in the paraffin industry during later years as the supply of pyropissite is practically exhausted. As shown by Raefler the coal is richest in pyropissite on the borders of several petty basins, the proportion decreasing toward the middle. In the larger basin near Zeitz in Sachsen, the proportion of pyropissite becomes negligible as one goes eastward, but it increases again farther east, beyond the central line of the basin. The origin of the material is obscure. Potonié, in describing the Senftenberg coal, says that many of the stumps, *Taxodium distichum*, are hollow and those at the bottom contain Schwelkohle in the cavity. But the Schwelkohle in hollow stumps is not confined to the bottom of the deposit though it is more abundant there. He thinks that this substance was produced by flow of resin, which must have been great in the wounded trees; but one has difficulty in conceiving how a stump, which had been dead long enough to become hollow, could still retain enough vitality to pour out a great quantity of resin for healing of its wounds. Whether or not it is a resin may be open to discussion. The microscopic study of the Weissenfels pyropissite by v. Gümbel led to no definite results but in the Sauforst material he found a great quantity of exines of pollen. The mode of its occurrence seems to suggest that it is not unrelated to the Lebertorfs in origin. Potonié regards it as resinous and its occurrence as layers or smuts in what he recognizes as autochthonous coal is explained by the suggestion, that these may mark dry places, where the exposed coal was removed by decomposition and the resin was left unmingled with foreign matter.

It appears wholly probable that pyropissite was an original constituent, not a product of chemical action during conversion of the vegetable material. Kraemer and Spilker thought it formed by green algæ while Witt believed that it was derived from spores. Graefe, considering the contrast between pyropissite and the undoubted resin, retinite, cannot regard a resin as the source of pyropissite, and concludes that wax-like secretions of plants were in chief part the original material. Treated with benzol, pyropissite yielded 69.5 per cent. of "bitumen," while good Schwelkohle yielded 27.3 per cent.—the calculation in each case being for the dry substance. Raefler

says that the poorer the coal is in benzol extract, the richer it is in resin. "Bitumen" from pyropissite contains no resin soluble in ether, but that from bitumen-poor coal may contain 25 per cent.

Bredlick²⁴⁵ states that Schwelkohle, when dried, resembles an earthy brown coal soaked in a wax-like bitumen. It is not homogeneous but consists of layers of richly bituminous lignite. It fuses at 150° to 200° C., thereby differing from fuel coal, which is infusible. He cites Riebeck on composition of pyropissite, which, ash-free, is carbon, 73.48, hydrogen, 11.70, oxygen, 14.80, while the associated fuel coal, according to Bredlick's analysis, has carbon, 64.78, hydrogen, 5.65, oxygen and nitrogen, 29.56. The several substances, when subjected to destructive distillation, yield

	Tar.	Water.	Coke.	Gas and Loss.
Pyropissite	64.2	7.7	16.3	11.8
Distillation coal	33.0	23.0	35.0	9.0
Fuel coal	5.0	63.5	25.0	6.5

Gas begins to pass off from pyropissite at 120° C. to 150° C., and the maximum temperature reached in the process is 640° C. The tar is of butterlike consistence when cooled, has gravity of 0.85 to 0.91, consists chiefly of paraffins and olefins, there being only traces of benzol and its homologues. This tar is fractioned and yields a paraffin free oil and paraffin wax, with a residuum. The last, about one third of the whole, is placed in another retort and heated to beyond the "cracking point." The gas from Schwelkohle is inferior; according to Graefe, its composition is: Carbon dioxide, 10.9; heavy hydrocarbons, 1.1; oxygen, 6.3; carbon monoxide, 8.5; hydrogen, 22.6; carburetted hydrogen, 6.4; ethane, 2.0; nitrogen, 42.2. The candle-power is from 8 to 12.

The Blätterkohle or Dysodil, which is a Tertiary Lebertorf, has been found in Sicily, France, Bohemia and other countries, but the most important deposits are near the Rhine in the Siebengebirge. The composition of material from Westerburg, according to Casselmann,²⁴⁶ is: Carbon, 62.80; hydrogen, 6.76; oxygen and nitrogen,

²⁴⁵ W. Bredlick in "Fuels Used in Texas," Bull. Univ. Texas, 307, 1913, pp. 169-178.

²⁴⁶ Cited by C. F. Zincken, p. 180.

19.43; ash, 11.00. This coal, which is utilized, like Schwelkohle, for production of oils and paraffin, yields, according to H. Vohl,²⁴⁷ by distillation: Water, 24.214; tar, 20.014; coaly residue, 46.326; gas, 9.446. The Blätterkohle of Rott yields 15 to 20 per cent. of tar on the large scale. This tar, when fractioned, gives: Photogen, 16; solarol, 24; paraffin, 20; hard paraffin, 4, from 100 pounds of tar.

Cannel-like coal has been reported from Washington, Alaska and Arkansas. That from Lewis county of Washington is extremely high in volatile, but no analysis is available. Analyses of two coals from Alaska show 71.3 and 81.26 of volatile. The Lester coal of Arkansas has 68.06 per cent., in the pure coal, and the best quality is said to yield 38 gallons of oil per ton. Lenses of cannel-like coal occur at Hoyt in Texas, but no analysis has been made. "Oil shale" of high grade has been found in New Zealand.

Analyses of brown coal, both proximate and ultimate, seem to be abundant enough for all purposes. Those from European localities are almost all from mines which have been long in operation and which yield coal proved to be marketable. In much of the areas within the United States, the coal has been mined in a small way to supply the owner's needs or those of a very small population; samples have been taken from these as well as from mines of great capacity, so that the reports from Government laboratories tell much respecting the variations in character. In almost every instance, the samples are prisms from the whole face of the bed, so that there is little information as to varying conditions during accumulation of the beds.

Comparatively few analyses of Pliocene coals have been reported. Hutton has given four for the Otago, New Zealand, basins and Hantken has given six for those of Hungary; reduced to pure coal basis, these are

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Volatile	51.6	71.1	56.3	53.3	20.1	22.2	23.7	25.0	27.4	46.0
Fixed carbon.....	48.3	28.8	43.6	46.6	79.9	77.7	76.2	74.9	72.6	53.9

Hutton's specimens were air-dried and contained from 11 to 16 per

²⁴⁷ Cited by Heusler, p. 133.

cent. of water. The ash is from 2.80 to 29.58. The samples were evidently selected specimens and Hutton seems to think that the selection was not always judicious. The water in Hantken's samples varies from 17.57 to 27.2 and the ash is low, barely 5 per cent., except in No. IX., where it is almost 20 per cent. of the dried material. No relation appears here between the quantity of ash and that of volatile matter.²⁴⁸

Von Ammon²⁴⁹ published several ultimate analyses from mines in Bavaria;

	I.	II.	III.	IV.	V.
Carbon.....	68.64	69.42	62.76	69.70	65.90
Hydrogen...	6.56	6.38	4.91	5.70	5.32
Oxygen.....	24.79	24.20	32.29	24.90	28.68

No. I. is a briquette with 10 per cent. of water and 13.21 of ash; No. II. is a fresh specimen from the Oettingen locality and contains 63 per cent. of water; No. 3 is lignit, bituminous wood, from Schwarzenfeld and No. IV. from the same place is woody; these have 41 and 36 per cent. of water but the ash is only 2.28; No. V. is a strongly dried brown coal, which has 24 per cent. of water and 9 of ash.

The number of analyses is small but they represent the best coals in the petty areas whence the samples were taken. Compared with peats, the proximate analyses show notable decrease in volatile, so great indeed in the Hungarian coals as to suggest the possibility of some metamorphic action. The ultimate analyses from Bavaria show an advance beyond mature peat in the carbon but it is not constant, for No. III. is poorer in carbon and richer in oxygen than some peats.

Miocene Coals.—Arnold has published two analyses from the Monte Diablo field in California, one representing a 5-feet cut at the top and the other, the lower part of the bed; Pardee has given two of the coal in southwestern Montana. These, made by the Bureau of Mines, show:

²⁴⁸ F. W. Hutton, "Geology of Otago," p. 97; M. Hantken, op. cit., p. 341.

²⁴⁹ L. v. Ammon, op. cit., pp. 18, 27.

	Volatile.	Fixed Carbon.	Sulphur.	C.	H.	O.	N.	Water.
I.....	54.57	45.43	5.64					
II.....	53.78	46.22	4.80	79.87	6.66	12.05	1.42	7.13
III.....	52.90	47.10	1.53	70.42	5.08	21.64	1.33	6.93
IV.....	59.20	40.80	2.15	72.20	6.73	17.93	0.99	10.00

The dips in the Monte Diablo area reach 70 degrees; the water in the coal is always low, sometimes not more than 3 per cent.; the ash is from 4 to 18 per cent.; but everywhere the coal seems to be very far from the bituminous grade. In southeastern Montana, the ash varies from 15 to 25 per cent.

The air-dried samples of Greenland coal, analyzed by Moss, as already cited, resemble a good bituminous coal, but the coal is a typical brown coal in all physical features. Miocene coals from Trinidad were analyzed by Percy, who obtained

	C.	H.	O and N.	Water.	Ash.
I.....	72.98	4.75	22.95	16.80	3.90
II.....	72.20	5.40	22.40	17.65	2.40
III.....	80.11	5.51	14.35	20.50	2.10
IV.....	77.16	5.83	16.89	5.90	3.44

In every case, the specimen for analysis was taken from the outcrop; all are attacked energetically by caustic potash. Experiments in the Survey laboratory showed that No. IV cakes. Resins appear to be wanting.²⁵⁰

A. S. McCreath's analyses of coal from the Miocene of Advent Bay, Spitzbergen, gave for different parts of the bed

	Water.	Volatile.	Fixed Carbon.	Sulphur.	Ash.
Upper part ..	3.310	19.790	62.763	0.467	13.670
Lower part ..	4.696	28.560	57.171	0.413	9.160

N. Dubois determined the ultimate composition of slack coal from the lower part of the bed, thus: Water, 4.14; carbon, 67.88; hydrogen, 4.05; oxygen and nitrogen, 11.90; ash, 12.03, or about 83 per cent. of carbon and 14 of oxygen in the pure coal. The notable features

²⁵⁰ G. P. Wall and J. G. Sawkins, "Trinidad," etc., pp. 123, 126.

are the low water throughout and the great difference in volatile of the two parts of the bed, more than 9 per cent. in the pure coal. This coal is very similar in appearance to many Carboniferous coals but it is attacked by caustic potash to an unusual degree.²⁵¹

Von Ammon²⁵² reports analyses from the small Miocene area in Bavaria, which exhibit much variability in composition.

	C.	H.	O and N.
I	49.01	5.15	45.82
II	70.93	4.25	24.81
III	60.43	4.47	35.08

The ash varies from 3 to 28 per cent. and the sulphur from 0.40 to 8 per cent. The first and third are very similar to peat in composition; the second is a Pechkohle from Schwarzen Moor.

The Grottauer coal of Bohemia contains, according to Katzer, 50 per cent. of water when freshly mined; dried at 110° C., it has carbon, 53.22, hydrogen, 5.56, oxygen and nitrogen, 37.95, ash, 3.97. The sulphur, as pyrite and in organic combination, sometimes reaches 3.84 per cent.

The Hungarian coals show considerable variation in composition. Nendtvich²⁵³ gives analyses from two beds thus:

	Water.	Volatile.	C.	H.	O and N.
Rudolphilager	18.68	49.11	70.849	4.715	24.445
	17.00	44.02	72.185	5.185	22.630
Josephilager	17.82	67.00	72.490	5.175	22.235
	17.10	54.00	71.360	5.095	23.545

These are from near Oedenburg; having been made according to the same method, they are comparable. They make clear that for comparisons one needs both ultimate and proximate analyses. The second from Rudolphi and the first from Josephi have almost the same ultimate composition, yet the latter yields about 23 per cent. more volatile than the former, showing that it has very different constituents. The analyses for each are from different portions of

²⁵¹ In *Annals N. Y. Acad. Sci.*, Vol. XVI., 1905, pp. 86, 87.

²⁵² L. v. Ammon, op. cit., pp. 62, 64.

²⁵³ C. M. Nendtvich, "Ungarns Steinkohlen," etc., pp. 40-44.

the bed. The ash varies from about 2 to 5 per cent. Hantken²⁵⁴ gives three analyses, which are equally illustrative; one is of coal from Édéleny and the other two from near Brennbérg.

	C.	H.	O.
I.....	53.85	4.21	41.94
II.....	71.92	4.95	23.53
III.....	71.90	5.14	22.89

These are all used as fuel; at Édéleny, the ash varies from 15 to 21 per cent. and the water from 21 to 61 per cent., so that the fuel is of decidedly poor quality; but at Brennbérg, the water does not exceed 18 per cent. and the highest ash is 3.45. These Miocene deposits are confined to very small areas.

Oligocene Coals.—These are of great importance in Prussia and in Hungary. Hantken²⁵⁵ has given proximate analyses of coals from the Zsil valley and from two parts of one mine near Gran:

	Water.	Fixed Carbon.	Ash.	Volatile.
I.....	4.83	58.50	6.55	36.67
II.....	14.09	59.53	3.55	22.53
III.....	12.727	38.035	8.217	40.921

Ultimate analyses from two localities in the Gran area, including the mine already referred to, have been given by Hantken and four others were published by Nendtvich:

	C.	H.	O and N.	Volatile in Pure Coal.
I. Szt. Ivan.....	64.92	4.94	30.10	
II. Gran.....	69.30	4.80	27.00	27.45
III. Gran.....	68.58	4.67	26.75	51.82
IV. Tokodt.....	67.495	4.70	27.80	31.30
V. Sarisap.....	67.85	4.83	27.22	38.77
VI. Csolnok.....	71.55	5.19	23.25	47.44
VII. Zsemli.....	71.89	4.79	23.31	40.45

The two coals from different parts of the mine at Gran have practically the same ultimate composition, yet in the pure coal there is a difference of 23 per cent. in the volatile. The contrasts are not

²⁵⁴ M. Hantken, op. cit., pp. 315-325.

²⁵⁵ M. Hantken, pp. 247, 259, 260, 262, 280, 286, 289; C. M. Nendtvich, p. 32.

so great in the coals analyzed by Nendtvich, but there is a difference of 7 per cent. in the volatile of two coals with essentially the same ultimate composition. The water in these Hungarian coals is from 4.83 to 17 per cent. and the ash from 4.23 to 11 per cent.

The coals of Brandenburg, in the region studied by Plettner, show notable variation, according to analyses reported by Zincken;

	C.	H.	O and N.
Perleberg, Erdkohle.....	66.32	5.20	28.48
Frankfurt a. O., Knorpel.....	65.60	5.36	29.04
Neudorf, Formkohle.....	60.00	6.56	33.44
Fürstenwalde, Formkohle.....	70.64	5.22	24.14
Knorpelkohle.....	68.37	5.47	26.16

A great part of the Sachsen coal is Formkohle, which according to analyses by Karsten and Bredlick, cited on an earlier page, contains from 62.74 to 64.32 of carbon and the oxygen varies little from 30 per cent. The analyses of the Brandenburg coals seem to indicate that the composition and the physical structure of the coal are not related, Formkohle being highest and lowest in carbon as well as in oxygen. These Oligocene coals differ not much from mature peat in their composition.²⁵⁶

Katzer analyzed two samples from an opening in the Läufer bench of the bed near Banjaluka in Bosnia, which show no great variation;

	C.	H.	O and N.
I.....	74.51	5.08	20.41
II.....	71.83	4.96	23.11

The water is from 21.82 to 29.05 and the ash, 7.40 to 8.45; sulphur is high, from 6 to 7 per cent.

The Oligocene coals of British Columbia are, in many cases, bituminous; the region being more or less affected by eruptive rock. It is not certain that the analyses reported give any clear conception respecting the general character of the coal, as the samples analyzed were selected from the outcrops.

²⁵⁶ C. Zincken, pp. 28, 29.

Eocene Coals.—The analyses of Southland coals in New Zealand, reported by Hutton, are all proximate; they show the volatile varying from 39 to 63.74 in the pure coal, while the water is from about 15 to 17 and the ash from 2.80 to 12.45 per cent. The samples appear to have been selected and not to be representative of the whole bed. No relation appears here between the proportion of ash and that of volatile. Zincken has given an analysis of the English Bovey Tracey coal, apparently by himself, and Dana²⁵⁷ has published an analysis by Vaux. Ash and sulphur free, these are

	C.	H.	O and N.
I	69.95	5.93	24.11
II	69.52	5.90	24.56

The Eocene coals of Texas are mined extensively at many localities and Phillips and Worrell²⁵⁸ have made numerous analyses, the samples having been collected in all cases in accordance with the official method. The composition of these coals varies greatly, even in a single bed within a limited area. The conditions are clear from comparisons of the samples taken from several mines near Rockdale in Milam county. All are reduced to pure coal basis except for water and ash, which are for the coal as received:

	Water.	Ash.	Volatile.	Fixed Carbon.	C.	H.	O and N.
1538....	32.79	10.70	61.8	38.1	69.71	5.54	24.74
1539....	34.72	11.76	60.8	39.1	73.63	5.48	20.87
1540....	32.27	12.05	74.3	25.5	67.36	4.99	21.64
1541....	33.63	18.27	86.2	13.7	72.84	5.07	22.08
1542....	31.52	9.45	71.7	28.2	67.38	5.50	27.11
1543....	29.07	26.47	54.2	45.7	77.11	5.46	17.41

The samples are all from the same bed and are in close proximity; it is clear that no relation exists between ash and volatile matter. It is equally clear that the conditions were not the same throughout the basin during accumulation of the peat. This appears from the

²⁵⁷ C. Zincken, p. 28; J. D. Dana, "Manual of Geology," 1895, p. 662.

²⁵⁸ W. B. Phillips and S. H. Worrell, "The Fuels Used in Texas," pp. 85-89, 91, 92, 98, 100.

variation in percentage of the ash; but it is more apparent when one considers the composition of the ash in the several samples:

	Silica.	Alumina.	Ferric Ox.	Calc. Ox.	Magnes. Ox.	Sulphuric Acid.
1538.....	21.64	16.20	11.10	25.23	4.36	18.01
1539.....	33.06	16.77	8.47	23.00	1.28	17.10
1540.....	27.44	28.87	24.85	7.00	0.00	10.45
1541.....	23.20	11.94	5.08	38.17	1.00	7.79
1542.....	42.20	23.02	2.02	15.93	2.12	12.81
1543.....	47.04	23.18	18.32	6.64	0.00	4.58

In these coals one has another illustration of indefiniteness of analyses as indications of the actual composition of coal. Nos. 1539 and 1541 have almost the same ultimate composition, yet there is a difference of more than 25 per cent. in the volatile.

Analyses of coals in the Wyoming-Montana-North Dakota region are numerous. Taff and Wegemann cut samples in the Sheridan and Barber fields. Ten beds were sampled in a vertical section of about 1,900 feet. The variations in composition are less than those found within a single bed in the Rockdale area of Texas. The volatile in the lowest bed is 46.30 and that in the highest is 47.67; but in one midway in the section it is 44.69, and in the one next above it is 53.20, while in the next to the highest it is only 43.97. The carbon varies from 74.37 in the lowest bed to 70.97 in the highest, but in a bed almost midway in the section it is 71.96. The oxygen is 20.42 in the lowest bed and 22.95 in the highest, but is lowest in an intervening bed. The coal throughout this region appears to be remarkably free from inorganic matter, as the ash varies from 4.10 to 9.95 per cent. of the dry coal and it is usually less than 7 per cent.²⁵⁹

Somewhat farther north, in the Red Lodge field of eastern Montana, samples were cut by Woodruff and were analyzed at the same laboratory. Eight analyses were made of six beds exposed in a section of approximately 475 feet. The volatile is from 37.35 in the lowest bed to 45.85 in the highest; but in another analysis, the lowest bed shows 43.35 and the fifth bed, ascending, has but 42.66. The carbon is 72.66 in the lowest and 74.41 in the fifth bed, while in the

²⁵⁹ U. S. Bureau of Mines, Bull. 22, 1913, pp. 307-309.

same beds the oxygen is 20.77 and 16.94 in the two analyses of the bottom bed while it is but 17.85 in the fifth. The ash is from 6.02 to 13.31 per cent. of the freshly mined coal, which contains 8.60 to 11.69 of water. Much of the coal, according to these analyses, would be regarded as inferior. In this field, as in the Sheridan, there is no relation between ash and volatile and comparison of analyses shows that position in the section is not very important. Proximate analyses from the Miles City field in Montana tell the same story, for the volatile varies from 42.49 to 49.60 in sound coal from the lowest bed, while a single analysis of crop coal from a bed, 800 feet higher, shows 48.09. Water in the lowest bed is from 29.25 to 43.70, while that of the highest is 35.51.²⁰⁰

Analyses were made of 7 samples cut in the Snyder mine near Glendive on the eastern border of Montana.

	Water.	Ash.	Volatile.	Fixed Carbon.	C.	H.	O and N.
2423	39.94	5.61	45.40	54.60			
3812	34.55	7.20	60.67	39.33	72.79	4.74	20.58
3815	33.65	6.90	49.84	50.16	67.87	3.97	26.80
3816	34.89	8.07	76.23	23.77	73.04	4.43	20.20
3817	31.26	6.80	68.49	31.51	70.92	4.07	23.72
3819	33.06	8.33	51.70	48.30			
3820	33.06	6.26	65.62	34.38			

Ultimate analysis was made of only four samples. In all cases, sampled by the official method, the coal is sealed in waterproof cans at once, so that it reaches the laboratory in fresh condition.

The ash varies in this small mine from 8.62 to 12.44 per cent. of the dried material; no relation exists between it and the volatile; 3816 and 3819 have practically the same ash, 12.39 and 12.44, but there is almost 25 per cent. difference in the volatile. 3815 and 3816 have almost the same ultimate composition, but their volatile differs by almost 16 per cent.

The Leonard and Smith samples are from eastern North Dakota, and their bed *C* is taken to be about 300 feet above the Glendive bed; bed *G* is somewhat more than 250 feet above *C*.

²⁰⁰ The same, Bull. 22, pp. 124-126.

	Water.	Ash.	Volatile.	Fixed Carbon.
2428 <i>C</i>	38.45	5.69	50.16	49.84
5779 <i>E</i>	34.50	7.51	51.05	48.95
5782 <i>E</i>	35.72	8.86	57.53	42.47
5782 <i>F</i>	35.40	5.64	64.86	35.14
5784 <i>F</i>	43.51	6.39	50.37	49.63
2427 <i>G</i>	29.78	6.56	50.74	49.26

No ultimate analyses of these samples were made, but the proximate analyses suffice to show the great variability in conditions under which the coals accumulated; there is notable difference in ash; in the two analyses of coal bed *F* one finds a difference of more than 14 per cent. of volatile.

The coals of the state of Washington have great economic importance and a great mass of analyses is available. In that state one finds all grades of coal from peat-like material to graphitic anthracite within the Eocene column; at many localities the coals yield coke of excellent quality. One may select only a few of the analyses as illustrating the variations. In King county the water is low, rarely exceeding 12, usually below 9 and in a great number of cases is below 6 per cent. in the freshly mined coal. The ash is high, not often below 12 and very frequently above 20 per cent. in the dry coal. The first five analyses, which follow, are from the several beds near Issaquah and are of subbituminous coal; the sixth is bituminous and the seventh is of coking coal from Bayne.

	Water.	Ash.	Volatile.	Fixed Carbon.	C.	H.	O and N.
8544 I	14.2	13.59	40.9	59.1	76.51	5.66	17.34
8445 II	13.8	20.53	47.3	52.7	74.77	6.00	18.51
11736 III	15.9	11.4	48.4	51.6			
11737 IV	16.5	24.4	52.4	47.6			
8543 V	15.1	13.36	39.9	60.1	75.52	5.41	17.55
9114	4.9	4.74	46.2	53.8	79.96	5.86	13.67
9485	4.2	11.62	38.3	61.7	81.52	5.65	12.30

At Ronald in Kittitas county, a coking coal is found with composition differing very slightly from that of the coal at Bayne. In Pierce county, coking coals are mined at many places with 3 to 5 per cent. of water in the fresh coal; the ash is rather high in some of them,

reaching even to 16 per cent. of the dried coal; not a few of these coals have 84 to 87 per cent. of carbon. But not all of the beds yield caking coal, even where its composition is closely similar to that of the others.

The coals of Lewis county show extremes of variation, for there one finds anthracite with 6.8 of volatile and 93.2 per cent. of fixed carbon in the pure coal, whereas at Mendota the coal is lignite with 20 per cent. of water and 73 per cent. of carbon. At Ladd the coals are bituminous and that from No. 2 is coking. It has 4.1 of water and 84.62 of carbon. It yields 34.2 per cent. of volatile from the pure coal. The other beds mined on this property have only 6 to 8 per cent. of water but the volatile is much higher, 43 to 48 per cent., and they are not caking. The ash throughout is high, 18 to 26 per cent. of the dry coal.²⁰¹

Igneous rocks are reported as cutting the coal bearing rocks at a few localities in King and Pierce counties, but for the most part the variation in the coals is regional and apparently is not due to local causes.

The Alaskan coals show all types from lignite to anthracite. The anthracite coals are in the Bering River region where the carbon content at times reaches 90 per cent.; but in the same region are bituminous and semi-bituminous coals. The lignitic type, however, prevails in the greater part of the territory.

	C.	H.	O and N.	Volatile.
I.....	67.45	5.27	26.63	64.44
II.....	69.08	5.28	25.16	50.86
III.....	68.77	5.02	25.93	50.53
IV.....	68.47	5.53	25.37	55.15
V.....	69.57	5.04	24.66	54.41
VI.....	64.60	5.44	29.55	59.16
VII.....	69.89	5.07	23.56	45.84
VIII.....	64.43	5.39	29.73	58.93
IX.....	69.59	5.19	24.78	53.55
X.....	67.40	5.47	24.71	56.97

At Coal Harbor, Unga of Dall's descriptions, in western Alaska, the analyses give for the coal, ash and water free: Carbon, 68.76; hydrogen, 5.30; oxygen and nitrogen, 24.89; volatile, 50.29.

²⁰¹ E. E. Smith, U. S. Geol. Survey, Bull. 474, 1911, pp. 42, 43, 48, 51, 64, 65, 66, 67.

On the borders of Kachemak Bay, farther east, ten samples were collected which have the composition shown in the preceding table, calculated after the same method:

Number VII. gives the composition of pebbles of lignite forming part of a conglomerate at the bottom of the Kenai (Eocene) in this district.

Nine samples were cut from the bed on Chicago Creek in the Seward Peninsula, which is 88 feet thick. In each case the sample represents a 12-foot cut. The results of analysis are:

	C.	H.	O and N.	Volatile.
I.....	71.69	5.01	22.18	44.84
II.....	71.25	4.85	23.02	45.89
III.....	70.78	5.05	22.96	44.96
IV.....	70.41	4.72	23.62	43.98
V.....	74.82	4.71	19.43	43.83
VI.....	69.33	4.61	24.41	44.70
VII.....	67.32	4.85	25.90	46.73
VIII.....	68.56	5.01	23.77	46.25
IX.....	68.68	4.83	24.46	46.51

In the Kachemak area the moisture in freshly mined coal varies from 17.44 to 28 per cent. and the ash is from 10.50 to 20.34 per cent. of the coal, dried at 105° C. But in one sample it is only 7.81. In the Chicago Creek bed the moisture is from 32 to 42 per cent. of the fresh coal and the ash is from 5.77 to 6.49 in dried coal from the upper half of the bed, as represented in analyses I. to IV., but in the remaining analyses it increases, becoming 9, 11, 31, 21 and 26 per cent., fractions being omitted.

The Kachemak analyses show that the carbon content varies from 64.60 to 69.59, but the volatile is from 50.86 to 64.44. Coals with almost exactly the same ultimate composition differ about 5 per cent. in the volatile. The Seward analyses prove great uniformity in composition of pure coal throughout the immense bed, the variation in carbon being only from 68 to 71, except in one cut, midway, where the maximum of 74 per cent. is reached. The volatile is greatest in the lowest third, where the ash is greatest; but there is no relation between the ash and the volatile; for in IX. the ash is 26.15 per cent. of the dry coal and the volatile is 46.51, while in VII. the ash

is 31.70 and the volatile is 46.73; in II. the ash is 5.77 and the volatile is 45.89.

Summary.—It is now in place to gather the facts presented and, if possible, to ascertain how far they may be related to the problem in hand.

The testimony throughout shows that Tertiary coal beds are notably limited in extent, their area varying from a few square rods to several hundreds of square miles—in some cases apparently even to 2,000 square miles; the extent being limited by the topography as the deposits appear, for the most part, to have accumulated in shallow ponds or in well-defined valleys. The lens-like form has been emphasized by almost all observers in every portion of the Tertiary. Unfortunately the details recorded for most localities are insufficient to justify an attempt at working out the history of any bed, known to exist within a large space. Detailed study is impossible at present in the United States and Canada, where alone the great beds are known, because those occur in regions with sparse population, where, for long distances, one must depend on imperfect natural outcrops or on the less definite lines of clinkered rock, caused by spontaneous combustion of the coal. The perplexity is increased by variations in thickness and composition of the intervening rocks, as well as by similar variations in the coal beds themselves, which make correlation extremely difficult. Several American observers decline to regard the coal deposits as continuous in large areas and prefer to describe "coal horizons." All agree as to the lens-like character of very many beds; even those who are unwilling to accept this for the great beds, frankly present the frequent changes into shale and the local disappearances of the coal as serious problems. Some observers have shown that the lenses often overlap, that a coal thins out and may be replaced by another at a few feet higher or lower. This feature, so characteristic of American localities, was recognized by Credner and by Raefler in the coals of Prussian Saxony.

The rocks intervening between beds of Tertiary coal may be conglomerate, gravel, sandstone, sand, shale, clay, limestone or alternations of such deposits. Ordinarily, these are of freshwater origin, but, not infrequently, one finds layers with brackish-water

fossils and occasionally a bed with typical marine forms. At most localities the bedding is irregular and the rocks seem, in many cases, to be composed of dove-tailing lenses; lenses of fine clay occur frequently. Sandstones and sands are cross-bedded in great areas; ripple-markings and mud-cracks have been reported from many places. Conditions in the western United States appear to indicate that these deposits were made on plains, where the sands drifted and where the water was collected in shallow pond-like areas. The gravels in many cases indicate filled channel-ways.

These intervening rocks frequently contain drifted materials. Leaves and stems of upland vegetation are found in the sands of Siberia; Collier saw cones of *Picea*, bones of mammals, land and freshwater shells in beds overlying Pliocene lignite on the Yukon; Grand'Eury observed wood, roots and spots of lignite at Budweis; Colenso in Wales described a deposit very like that of Alaska; the sections in western North America usually contain reference to these drifted plant remains. But not all the plant remains were transported; at many places they mark old soils of vegetation, surfaces where plants grew, but not long enough for accumulation of coal. There are many references to these in preceding pages and only one need be added. Darwin,²⁶² in a publication later than his "Researches," gave a detailed description of the petrified forest seen on the Uspallata range of Chili. The stumps, exposed in a small area, were in green and brown sandstone, which had been removed by erosion so as to show the erect stems in place. Fifty-two stumps were examined, projecting 3 to 5 feet—in one case 7 feet—from the surface. Whether or not they were rooted, he could not determine, as the lower part in every case was still buried in the rock. The dip was 25 degrees and the stems were vertical to the bedding. It was suggested to him that the trees might have been transported, but that explanation seemed insufficient; it might suffice for a single stump but not for a clump of 52 trees, which belonged to an inland coniferous flora, not to a coast vegetation. The conditions convinced him that erosion had laid bare only a small part of the forest.

Occasionally, lake marls, interrupted by beds of brown coal,

²⁶² C. Darwin, "Geological Observations in South America," London, 1846, pp. 202.

accumulated in great thickness, as in southern France. It is evident that some were made close to estuaries, for several observers have recorded that thick deposits, crowded with freshwater fossils, are interrupted by layers containing forms which are unquestionably marine. The intervals between Tertiary coal beds vary so greatly and so abruptly in thickness that, where natural exposures are the only dependence, correlation of beds in any area is difficult, often impossible.

The roof of a Tertiary coal bed may be composed of any kind of rock, transported or formed *in situ*. There are abundant illustrations of transition from the underlying coal to the roof rock, from accumulation of coal to final destruction of plant life on the bog surface, alternating laminæ of vegetable and mineral material testifying to the struggle between silt overflows and the dwindling bog. This faux-toit is a characteristic feature; at times it is merely a carbonaceous shale; at others it is a very impure coal. Very often the immediate roof is distinctly transported material with leaves, twigs and broken bits of wood, even fragmentary trunks of trees. It may be marine shale, rich in fossils, or it may be a marine limestone, as at Häring, containing bits of water-loving plants, such as *Salix*, *Erica* and palms. Or it may be sand enveloping erect trunks of trees, which grew on the dried surface of the bog, as at Senftenberg or near Friesdorf in the Cologne area. Grand'Eury²⁶³ remarks that the fossil forest in the roof of the great coal bed at Petroszeny, in Hungary, rivals that of Purbeck and that the trunks, erect, are rooted on the top of the coal, while around the stems at the bottom of the deposit are branches of *Taxodium distichum*, clearly fallen from the stumps. A similar condition is reported from localities in the United States and in Europe. At times, the roots of trees growing in the faux-toit, pass downward into the coal as described by D. White for a mine in Texas and by other observers in places where the stumps are rooted in the coal. Grains of coal are not rare in the roof or the accompanying rocks, showing clearly that a coal deposit had been exposed to erosion. In much of the Oligocene areas of Prussia, the original roof has been removed and has been replaced with late drift material. The gradual disappearance of coal-forming

²⁶³ C. Grand'Eury, *Comptes Rendus*, T. 130, 1900, p. 1689.

conditions is shown very frequently by a faux-toit; but not rarely the passage from coal to roof is abrupt, which may indicate, perhaps, that peat-making had ceased for some time prior to the burial under transported material.

The coal beds are rarely single; they are divided by partings into benches, which differ greatly in thickness and in composition, though there are beds which are remarkably uniform in composition throughout. The coal may be hard or soft, massive or laminated, and the several types may be in separate benches or even in the same bench. Generally, the coal is hard enough to require the use of heavy tools in mining so that it comes out in lumps, Knabben- or Knorpelkohle of the Germans. This type is especially characteristic in the United States. But in somewhat extensive areas within Germany one finds abundantly the other type, Form-, Fein-, Rieselskohle of the various localities, fine-grained, earthy in appearance and but slightly coherent. All types of coal, enumerated by authors, may be found in a single bed or even in a single bench. Fragments of wood are numerous, lignite at one end where the annual rings are distinct, while at the other end they have been converted in shining Pechkohle, apparently without trace of vegetable texture. A similar condition is seen in many cases of replacement, for one part of a stem may be wholly silicified while the other remains wood. In such cases, the original structure frequently remains distinct, whereas in replacement with dissolved carbon compounds, as in Pechkohle, the structure disappears. The distribution of Formkohle in a bed is indefinite; it may occupy the whole space from floor to roof, interrupted only by partings; it may be at the bottom or at the top, or it may alternate with benches of other coals. Its mode of origin is discussed elsewhere by the writer.

Macroscopically, the coal consists of various fragments of organic and of inorganic origin, embedded in a structureless mass, in which the unaided eye can find no trace of texture; but under the microscope, this structureless mass proves to be minutely divided plant débris. Woody materials are often predominant, occasionally more than three fourths of the mass. Logs are reported from all localities, but they are distributed irregularly through the deposit, at least

as a rule. At times, prostrate stems as well as rooted stumps are abundant especially in the lower portions, but at others they occur within definite horizons in the higher portions; the smaller fragments are frequently converted into mineral charcoal. These conditions, observed in widely separated American localities, are similar to those observed in many European places, though, there, masses of logs are not so common as in the American lignitic coals; but the logs are found in all sorts of coal, Formkohle as well as Knorpelkohle and, many times, they are of enormous size. Prostrate logs are, with rare exceptions, compressed, often so compressed that it would seem as though only the bark remains, but erect stumps are very rarely compressed. Leaves and the strongly compressed stems appear as impressions on the structureless débris though occasionally, as at Bovey Tracey, leaves may form the great mass as slightly compressed logs do elsewhere. The logs belong mostly to conifers and they have been preserved because of the resin-content. The débris, formed from the softer, more readily decomposed plants and portions of plants, contains spores, pollen grains, bits of dicotyledonous plants as well as of the softer parts of conifers. The disintegration and decomposition of the material has led to enrichment in resins, as shown under the microscope. Replacement of wood is common, the replacing material being for the most part, silica, pyrite, calcium and ferrous carbonates; this replacement has been observed in the peaty material of the débris, giving the nodules, which Gothan and Hörich have termed torfdolomite.

Animal remains have been found in coal at many localities. Sedgwick and Murchison, as well as Anker, discovered bones of mammals in the Eocene bogs of Styria; Katzer saw teeth and bones of mammals in the Banjaluka coal; Fournet saw abundance of land and freshwater shells in the French lignite; v. Gümbel observed *Helix* in some layers of Pechkole in southern Bavaria. The dysodil or Blätterkohle of the Lower Rhine region contains many species of batrachians, fishes and insects, while that of southern France is closely packed with fish remains, retaining at some localities much of the original animal matter. Inorganic materials are normal constituents of coal; some of the admixture is due to silicious organisms,

for diatoms are of common occurrence, occasionally following important deposits; a greater proportion is derived from the mineral content of the coal-producing plants themselves; but when the quantity is considerable, the most of it is of extraneous origin. Pockets of sand and silt have been reported by almost all observers. The silt is often distributed intimately throughout the coal or it may be collected in thin laminae, such as render the coal worthless, or it may be in comparatively thick partings; even pebbles of rock have been reported from a few localities.

Brown coal deposits, with rare exceptions, are broken by partings. These may be so thin as hardly to be seen by the unaided eye, yet they are distinct, for the coal separates on their planes; they may be a foot or more in thickness and composed of any material transported or formed in place. Each definite parting is roof to the underlying, and floor to the overlying coal. Roots, leaves and freshwater, as well as land shells have been reported from clay partings in Hungary and Bosnia, leaves from New Zealand and Borneo and freshwater shells from shale and marly limestone partings in France. References to other regions are in preceding pages. Each parting is evidence of interrupted coal-accumulation; but its thickness at any place is no evidence respecting the duration of the period of interruption, for the thickness is a variable quantity. Russwurm notes a parting which increases from 0.5 to 4 meters within a short distance; near Gran in Hungary is one which is 1.9 meter in one mine but 17.45 meters in another, only a little way off; Evans has described one in Washington, which thickens from 4 to 90 feet within a horizontal distance of 3,200 feet, while in another direction it quickly decreases to 10 inches. Such variations are due to merely local causes as the deposits, for the most part, are of very limited extent. The changes are comparable to those observed in the rocks intervening between coal beds, often so great as to make correlation of the coals difficult. The partings, which consist largely of mineral charcoal, are important, as they appear to be often persistent throughout a basin; yet they are rarely more than half an inch thick. These indicate a positive change in conditions which made growth of vegetation impossible and led to exposure of the peaty surface to atmospheric

action. A layer of mineral charcoal and minutely divided inorganic matter may be the residuum from a considerable thickness of peat; the proportion converted into mineral charcoal and so rendered practically indestructible would be small compared with that wasted by oxidation and removed by the wind.

Evidence of long-continued interruption of ordinary peat formation is afforded by forest beds within the coal deposit. At Senftenberg, as shown by Potonié, the surface of the bog became dry enough, more than once, to permit growth of trees; in the Cologne-Linz area, the dryness was such and the period so long that a forest, containing trees with 1,600 annual rings, had full opportunity for development. In much of the Cologne region, the vast proportion of the stems are prostrate, but that condition is by no means evidence that they are in any but the place of growth. They are merely overturned trees as are those of the white cedar swamps of New Jersey or those in the cypress swamps of Florida or the bogs of Borneo. One layer in the Cologne-Linz district is a meter thick but erect stumps are present among the prostrate stems, as Horner and Heusler have shown. Trees of such immense size as those described by Horner indicate a very prolonged period of comparative dryness, during which the peat, as soil for the trees, was protected from wasting by offal dropping from the dense forest cover. A somewhat similar condition was noted by Wegemann in the Barber coal field of Wyoming.

The floor of coal beds is as variable as the roof, but it is usually clay or marl. The transition from the coal is occasionally abrupt, but in most cases the passage is gradual, through a *faux-mur*, consisting of alternating layers of coaly material and the *mur* rock. Very frequently the *mur* contains fresh water shells, that condition being reported from many places in all parts of the world. Land shells are not rare; they may have been floated in or they may mark drier places in the swamp. Leaves are found frequently in the marls and clays. The notable feature of the *mur* is the presence of roots attached to stems projecting into the overlying coal. At times the roots alone remain recognizable, the stems having been merged in the coal. Usually these are those of swamp types; but in cases

where the stumps project into the coal other forms may occur. The classic illustration is that at Senftenberg, described by Potonié, where one sees complete evidence of destruction of a forest by a transgressing bog. Kukuk's photograph of wholly similar conditions is equally conclusive. Not rarely the stumps had become hollow before entombment.

No complete statement respecting the flora of the brown coals can be made; the plants obtained from the associated rocks cannot be utilized as they are enclosed in rocks of transported material and represent, in part at least, the upland flora; they are as inconclusive as would be lists of forms found in the clays and sands which had slipped down on a swamp, to one endeavoring to determine the plants of peat. It is necessary to confine one's investigation to such information as can be obtained from the coal itself, though in some cases evidence from the enclosing shales may be utilized as illustrating prevailing conditions in the immediate vicinity.

The logs and stumps within the coal beds are almost invariably conifers. In Greenland and Spitzbergen, recognizable remains are rare in the coal and the logs are usually silicified; but the associated shale shows that, during its deposition, the prevalent types of the immediate vicinity were conifers and other forms of acid-loving plants, a swamp flora, so that swampy conditions prevailed in the area whence the shale material was drawn. The Pliocene coal of Hungary is crowded with stems of *Sequoia*; the Miocene swamp of Virginia contains *Taxodium*, *Nyssa*, *Salix*, *Quercus* and other types belonging to genera familiar in recent cypress swamps. At Bovey Tracey in the Eocene, ferns and *Sequoia* predominate, yet at the bottom of one bench there is a mass of dicotyledonous leaves. Fournet found a typical swamp flora in the Vion lignite, where he recognized birch, juniper, fir, cherry and walnut, with sedges and rushes. Daubrée, near Lobsann on the Lower Rhine, found that the mineral charcoal is from conifers while the peculiar fibrous coal, his lignite bacillaire, which forms the greater part of some deposits, is derived from Palms. At Senftenberg *Taxodium distichum* is the prevailing type in the coal, but in the upper layer are stumps of *Pinus* or *Picea*. Conifers and palms are the most abundant types in

the Hardt district of the Cologne-Linz region. The woody fragments in Brandenburg mines are practically all from conifers; in Sachsen, the fossil wood is coniferous, belonging almost wholly to the cypresses; but at Tanndorf, where the conditions are well shown, Penck found *Salvinia* and *Trapa* in the lower portions, succeeded by a layer with *Arundo*, which is followed by normal peat with *Betula* and *Palmacites*. Reuss's collections from the fetid limestone roof of the Häring coal show that the coal was formed at the head of an estuary for, mingled with remains of marine animals, it contained abundant fragmentary remains of *Salix*, *Erica*, palms and other swamp plants, which, it would seem, must have been torn away from the still living swamp on the shore, continuous with the buried swamp which has given the Häring coal. American localities tell the same story respecting the woody materials. Grand'Eury,²⁶⁴ in summing up the results of his studies, asserted that in the lignite areas of Tertiary age he had found as many stumps with roots and branches *in situ*, as in Carboniferous coal basins. From their position, even in the midst of rocks and limestones, it is to be presumed that the *in situ* roots are evidence of plants growing on bottoms subject to inundation. The flora shows instances of local variation, one striking illustration being that recorded by Heusler in the Cologne area.

Very few observers have given detailed record of localities where evidences of contemporaneous erosion are distinct. The writer has made careful comparison of sections preserved in basins of considerable magnitude and he is convinced that the variations in coal and the intervening rocks are such in many areas that they can be explained as due only to contemporaneous erosion. The absolute proof of such erosion cannot be secured except where coal mining has been well-developed—and there are few such localities in the American Tertiary. European basins are small and the petty variations due to contemporaneous erosion are easily overlooked. Very clear cases of such erosion have been reported from the interval rocks of Wyoming but in no case is the extent fully revealed. Evans has shown that in Washington some coal beds have suffered severely

²⁶⁴ C. Grand'Eury, *Comptes Rendus*, T. 138, 1904, pp. 666 ff., 740 ff.

and that, in considerable spaces, the coal has been removed and has been replaced with sandstone.

The intimate resemblance of many brown coal deposits to those of peat has been affirmed by many observers. Collier recognized the resemblance in Alaska and Washington as did Eldridge in Alaska; Haast was positive respecting it in southern New Zealand; several authors have described the Moor- and Mooskohle of Prussia and Bohemia; Gothan and Hörich have shown that the Torfdolomite of the Lower Rhine is merely mature peat replaced by inorganic matter; Smith and Travers²⁶⁵ described as peat an impure brown coal underlying the London clay. In many places the coal has been found resting on the characteristic reed beds.

Few students have made minute investigation of the structure and succession of individual beds. Penck's observations at Tannndorf have made clear that the brown coal at that place is in a lake basin; the muddy floor afforded roothold for floating plants, on whose débris rushes and other plants of similar habit grew, until the surface became such as to permit growth of shrubs and trees. Others have reported the occurrence of swamp plants in the brown coal, but they have not said anything about their vertical distribution in the deposit. Similarly, the presence of land and freshwater shells has been noted by numerous writers, but there is rarely any information as to their distribution in the bed. All that one may assert is that these indicate the existence of pools or ponds in the marsh. Expansion of the accumulating area by transgression, after the manner of swamps, is distinct at many places. Stohr has shown that in a part of Prussian Sachsen, the deposit began on an irregular surface as a number of separate lenses, which often became united by crossing the dividing ridges; so that the coal is from 0 to 20 meters thick, being thinnest on the low rolls separating the narrow troughs. D. White's description of conditions at Lehigh, North Dakota, is wholly similar; the greatest thickness is in the hollows of the floor and the coal becomes thinner toward the "rise." At Senftenberg and Orebkau, as appears from description by Potonié and Russwurm, transgression upon forests is clear. At Senftenberg, the forest was living when the marsh

²⁶⁵ W. Smith and M. W. Travers, *Journ. Soc. Chem. Ind.*, Vol. XI., 1892, p. 591.

invaded it, and the stems, still erect, extend into the coal; but at Orebkau, the condition appears to have been different. There, logs increase downward until at the bottom they constitute practically the whole mass. The forest growing in loose material must have been overthrown, for in the mines examined by Russwurm, no erect stems were seen. Many beds of brown coal seem to be wholly without tree trunks, just as there are many peat bogs without fragments larger than a twig; these had not reached the stage of tree-growth. Interruptions in growth are equally characteristic of peat bogs and brown coal beds. Some are shown by partings containing much mineral charcoal, others by partings of transported mineral matter, while others still by the forest layers. At Bovey Tracey, a great mass of leaves in the lower part of a thick bench is the remaining evidence of a dicotyledonous forest, whose non-resinous stems have disappeared. A succession of forests is shown at Senftenberg, even to the last, which was entombed in the covering sands as was that at Wurzen in Sachsen. The great forest bed of the Hardt area marks a long, though not total interruption; growth of normal peat ceased for the time, but accumulation most probably continued; offal from coniferous trees accumulates to notable thickness in many parts of the world without injury to the trees; Capps has shown that in Alaska, where the plane of perpetual frost is at only a few inches below the surface, the gigantic spruces adjust themselves to the conditions and throw out new sets of roots as the peat surface rises.

The benches of a coal bed often are dissimilar. One finds no evidence of widespread climatic changes during the period of a single bed's growth. In most cases, there is evidence of notable variation in moisture conditions and dryness appears in some localities to have prevailed for long periods; but there is no evidence that these variations were due to any but local causes. They are much like those which may be seen in almost every peat deposit. At Bovey Tracey, one bench is composed almost wholly of fronds of ferns while another is a mass of *Sequoia* stems; near Budweis, the upper bench contains stems completely coaled, while the lower bench is composed mostly of the imperfectly changed Moorkohle. Hantken has described a bed of which the upper part is woody, crowded with

Sequoia, while the lower part is hard coal. At Orebkau, the upper bench is Knorpelkohle, with very little wood, while the lower bench is Formkohle with much wood. Variations of similar type are reported from American localities and they are such as are familiar to students of peat deposits. They are so characteristic that one finds it difficult to avoid the conclusion that, as in peat bogs, the process of conversion was arrested in some benches while it continued in others. It seems hardly possible that the differences developed after burial, as conditions since that time must have been practically the same for all portions of the deposit.

The differences in physical features are accompanied by differences in chemical composition. The lower portion of the coal bed on Advent Bay, Spitzbergen, has 9 per cent. more volatile than is found in the upper portion. Coals from different parts of the same mine show even greater contrast; 18 per cent. near Gran in Hungary, 23 near Brennborg in the same kingdom, 35 at Glendive in Montana; and similar variations are shown by analyses of samples from neighboring mines on the same bed. The ash content tells the same story; in six mines on the same bed, near Rockdale, Texas, the ash varies from 9.43 to 24.67. The comparison is more instructive when one considers the composition of the ash, for the samples analyzed were prisms representing the full thickness of the seam, only such partings being removed as should be separated before shipment of the coal. The silica is from 21 to 47 per cent., alumina from 12 to 28, ferrous oxide from 2 to almost 25, lime 6 to 38 and sulphuric acid 4.58 to 18.01. These samples were taken in an area of probably not more than 2 or 3 square miles. It would appear that conditions during accumulation varied greatly in the different parts of even small areas, just as they do in the swamp areas of this day.

Sapropelic or Lebertorf material is an important constituent of many swamps, though there are very many in which no trace of it exists. It has been reported occasionally from the Tertiary coal. Dall obtained at Amalik Harbor, Alaska, a dull coal which contains 81.26 per cent. of volatile matter; at Mendota in Washington there are lenses of what appears to be Lebertorf, the coal having all the features of cannel and burning with a long smoky flame; lenses of

wholly similar material were observed by D. White at Hoyt, Texas; the same observer has described the cannel-like material of the Lester bed in Arkansas, very rich in oils and in gas of high candle-power; it is rich also in spores and pollen exines. Tertiary "oil shale" of high grade is reported from New Zealand. The mode of occurrence and the chemical as well as physical constitution indicate very close relationship to the Lebertorfs. Pyropissite presents some problems not yet wholly solved, though they have attracted attention from many students; but there appears to be little evidence to support the hypothesis that it is merely the resin of the original plants, concentrated by physical agencies during transportation of the more or less converted peat or brown coal; while there is much to suggest that it is related to the Lebertorfs. The condition is different in the case of dysodil or Blätterkohle; that is without doubt of sapropelic origin. It occurs in lenses, sometimes at the bottom, at others in the upper portion of a bed, while, occasionally, it forms the whole mass. This contains abundant remains of aquatic animals, spores, pollen and, at times, is rendered almost worthless by the great proportion of diatomaceous earth.

Haidinger, in studying the Faserkohle from the Häring deposit, discovered that it contained a material, which he believed was introduced when in the condition of dopplerite, a soluble constituent of peat; D. White in several publications has maintained that the jetified wood, so abundant in the xyloid Tertiary coals of the United States, owes its character to the infiltration of dissolved products of vegetable decomposition. Glöckner reached the same conclusion respecting the "Glanzkohle" of Zittau. Von Gümbel regarded the "Carbohumen" or cementing material of brown coal as merely dopplerite which had passed over to the insoluble condition. Dopplerite, as the analyses show, is not a true mineral but is a mixture of various humic or humic and ulmic compounds, which after losing an indefinite proportion of water, is so changed that it cannot regain plasticity even by prolonged submergence in water. The zittavite of Glöckner appears to be a wholly similar substance; the terms dopplerite, Carbohumen and zittavite indicate the geological horizons of the occurrence.

The carbon content of brown coal varies; in a general way it gives proof of great advance over peat, yet in many localities the process of conversion stopped short of the stage reached by most of the fuel peats of which analyses are available. Pliocene coal of Bavaria has from 62 to 69 per cent.; Miocene coal from one mine in Bavaria has but 49, the Édéleny coal of Hungary has but 54 and the Grottau coal in Bohemia has 53; but in other localities in Bavaria the carbon is almost 71 and near Brennberg in Hungary it is 72. The Oligocene coal in the Gran-Comorn district of Hungary shows 65 to almost 74; the Brandenburg coals have 60 to almost 71, the Zeitz area of Sachsen 64.78, and the Cologne area only 62. Eocene coal of Bovey Tracey has almost 70; coal at Rockdale, Texas, contains 67.36 to 77.11 in samples from several mines on the same bed. In the northern areas within the United States, there are few analyses showing less than 70 and some reach 75, but in Alaska coal from most of the beds has from 64 to 70. In Alaska and Washington, there are localities where the carbon content is much higher, but those do not concern the matter in hand, as there is reason to look upon them as more or less metamorphosed.

Beyond all question, there is at most localities distinct evidence of progressive enrichment in carbon with loss of oxygen as one descends in the scale. The extremes of carbon content in peat are 40 and 64; in the Miocene, 49 to 72; in the Oligocene, 58 and 70, in the Eocene, 64 to 79. At the same time one must recognize that, as in peat deposits, the progress of change was checked in some localities at a much earlier stage than in others.

ON ETHNOLOGICAL TESTS OF SENSATION AND PER-
CEPTION WITH SPECIAL REFERENCE TO TESTS OF
COLOR VISION AND TACTILE DISCRIMINATION
DESCRIBED IN THE REPORTS OF THE CAM-
BRIDGE ANTHROPOLOGICAL EXPEDITION
TO TORRES STRAITS.

By E. B. TITCHENER.

(*Read April 7, 1916.*)

The work of the Cambridge Anthropological Expedition to Torres Straits was planned to include a psychological study of the native population. The "equipment of a small psychological laboratory" was taken out to Murray Island and set up in the disused missionary house; and the tests made, there and elsewhere, were conducted by Messrs. Rivers, Myers, McDougall and Seligmann. The leader of the expedition was already known to the natives, whose goodwill was thus assured.¹ On the whole, I suppose that field-work in psychology has never been done under better conditions: the apparatus had been considered and chosen beforehand, the experimenters were competent, the natives were amenable. Yet I think that no home-staying experimentalist can read the psychological part of the Report with satisfaction. At any rate, the impression left by my own repeated reading is that the tests were inadequate to their purpose.

In the present paper I criticize, as severely as I can, two samples of this field-work. I have chosen tests whose results have been widely quoted, and I have chosen them for their strength rather than for their weakness. It is true that the Report is fifteen years old; and it is true that, during the past fifteen years, experimental psychology has made great methodical advances, social anthropology has grown

¹ See Reports of the Cambridge Anthropological Expedition to Torres Straits, II., 1901, v. f., 1 ff. This volume is referred to, in later notes, by the letter R.

apace, and psychotechnics has come to the forefront of discussion. It does not follow, however, that my criticism is out of date. For field-psychology is still in its first beginnings. Something, no doubt, has been learned; and an expedition that we should organize today would hardly be content to repeat the programme laid out for Murray Island. The labor and ingenuity spent upon mental tests have not been simply thrown away. I doubt, nevertheless, whether the new expedition could be certain of improving, in any material way, upon the work of its predecessor; and if this doubt is well founded—nay, if there is any doubt in the matter at all—then a detailed criticism of the older tests, supported as mine is by collateral experiment, ought to be of service.

It is, perhaps, not out of place to add that I am criticizing experiments with which I have the greatest sympathy. My own lifelong interest in psychology came by way of anthropology; and if I chose the laboratory in preference to the field, that was only because I was convinced that the first necessity of experimental psychology, as a science, was the standardizing of instruments and procedures. I realize that time presses; the primitive stocks are fast changing or disappearing. I realize, too, the difficulties of work in the field: the unaccustomed mode of life, the lowering of health, the indifference and trickiness of the native, the frequent breakage or failure of apparatus and the impossibility of replacement or of proper repair. My criticisms are thus offered in the friendliest spirit; and my aim is to lead up to positive suggestion rather than to conclude with a merely negative result.

One further point, and these introductory remarks may be ended. The critic of tests performed in the field is at a serious though unavoidable disadvantage, in that he has nothing more to go upon than what the field-workers include in their report. When an experimental study is published by a laboratory, it is open to any other laboratory to repeat the work with observers of the same order of intelligence and training, by the same methods, with similar instruments. Tests made in Torres Straits cannot be thus controlled; the printed pages are all that we have. I have tried, nevertheless, to make parallel and illustrative experiments of my own. If the reader

finds them relevant to the issues discussed, the credit is largely due to the fullness with which the authors of the Report have written. They remind us, time and again, that human nature is much the same the world over. The old lady on Murray Island who, "by associations of some kind," gave her own and her friends' names when she was asked to name a set of colored papers, have we not met her—with all respect be it spoken—in our summer sessions? The man who was asked to arrange the colors in the order of his liking, and who handed them back in almost exactly the order in which they had been presented by the experimenter in an earlier test, is a fairly familiar figure in our laboratories. If, then, I presently compare the observations of my colleagues with those of a Papuan chief, I am not necessarily falling into absurdity.

I. THE DELICACY OF TACTILE DISCRIMINATION.

I begin with McDougall's experiment upon the limen of dual impression upon the skin. His conclusion is as follows: "These figures indicate that in the skin areas tested the Murray Islanders have a threshold of tactile discrimination of which the value, in terms of distance of two points touched, is just about one half that of Englishmen, or we may say in other words, that their power of tactile discrimination is about double that of Englishmen. And . . . we may assume that this result is true for all or most parts of the skin."² I shall try to show that the conclusion does not follow from the experimental data.

McDougall used "a small pair of carpenter's dividers with blunt metal points."

"These two points were applied to the skin simultaneously with light pressure lasting about one second. The subject was told to keep his eyes shut, and the area of the skin operated on was further guarded from his view. . . . He was told to say 'one' or 'two' according as he judged that one or both points touched his skin. . . . The threshold that I sought was . . . not that distance at which two points can be distinctly felt, but a slightly lower one, that distance at which they yield a sensation perceptibly different from that yielded by a single point.

"One point was applied in every experiment about as frequently as the two points. . . . In order to keep the attention and interest of the subject as keen as possible, I found it necessary to tell him after each answer whether

² R, 192, 195.

he was right or wrong, for in default of this precaution many of the subjects soon contented themselves with random answers."³

It is a minor but still a relevant detail of criticism that the metal points should have been replaced by hard wood or hard rubber. The metal points appeal to the temperature senses as well as to the sense of pressure. I pass, however, to more important things. It will be noticed that although, on general principles, "the procedure should be, as far as practicable, without knowledge on the part of the subject,"⁴ the method is in fact full of suggestion. The subject knows what is being done to him; he is to judge whether "one or two *points* touched his skin." The stimulus-error, with all that it brings in its train, is thus not only admitted but even welcomed. Secondly, the one-point stimuli are "about as frequent" as the two-point. The subject thus has recurring opportunity to check or control his dual judgments. And since he is told "after each answer whether he was right or wrong," the control is continually renewed and the difference between single and dual stimulation is continually emphasized.

The results obtained may be illustrated from the forearm-limens;⁵

MURRAY ISLANDERS.

Average of 50 men 19.8 mm. (median, 20; extremes, 40 and 2)
Average of 25 boys 14.0 mm. (median, 15; extremes, 25 and 2)

ENGLISHMEN.

Average of 23 men 44.6 mm. (median, 40; extremes, 90 and 10)

It is clear that the Englishmen have the higher average limen. It is also clear, however, that the range of the results is excessive. In the case of an elementary perceptive discrimination, we do not expect values that range between 40 and 2, or between 90 and 10 units of measurement. The results suggest, then, that different subjects may have been doing different things. Fortunately we have collateral evidence which not only confirms the suggestion but also indicates what the different things aimed at and done may have been.

The limen sought by McDougall was, it will be remembered, "not

³ R, 190 f.

⁴ R, 189.

⁵ R, 191 f.

that distance at which two points can be distinctly felt, but . . . that distance at which they yield a sensation perceptibly different from that yielded by a single point." It has long been known, however, that between the limits "point" and "two points" there are a number of distinguishable perceptive forms. Gates, working recently in my laboratory, distinguished "circle," "line" and "dumb-bell"; but there were slight differences within these categories; and there is no doubt that more such forms could be made out.⁶ Suppose, then, that an observer is set or disposed for "dumb-bell"; his limen will be relatively high. Suppose, on the other hand, that he is set for "circle"; his limen will be relatively low. In either event he will be reporting "a sensation perceptibly different from that yielded by a single point" and lying on the hither side of "two points distinctly felt"; but the limens will be the limens of two different perceptive forms, and therefore will not be comparable the one with the other. Here, I take it, is the principal key to the wide range of McDougall's results. Some of his observers judged "two" as soon as the impression of the points differed in the slightest degree from "one"; others judged "two" only when the points were on the brink of falling apart or had actually done so. If this inference is correct, the comparison of the Murray Islanders with the Englishmen is null and void.

I made, to test it, a rather venturesome experiment. With McDougall's instrument "it was not possible satisfactorily to apply the two points at an interval less than 2 mm."⁷ The æsthesiometers regularly used in my laboratory have hard-rubber points (diameter 1 mm.) which may be directly apposed. With our instruments, therefore, it is possible to employ a dual stimulation with a separation of 0 mm.; in other words it is possible to compare the impression of a single point with that of two apposed points. It occurred to me that I might be able, under the suggestive influences of McDougall's method, to discriminate these two impressions. I asked

⁶ E. J. Gates, "The Determination of the Limens of Single and Dual Impression by the Method of Constant Stimuli," *Amer. Journ. Psych.*, XXVI., 1915, 152 ff. M. Foucault ("L'Illusion paradoxale et le seuil de Weber," 1910, 124 f.) distinguishes six intermediate perceptive forms.

⁷ R, 191.

the first available experimenter to make up a haphazard series of 32 stimuli, 16 dual and 16 single, and to perform the test upon my forearm in McDougall's way. The experimenter was wholly unpractised, so that I worked under unfavorable conditions: the time of impression varied, its intensity varied, the instrument was set down sometimes slowly and sometimes with impact, the ready-signal was often omitted, and so forth. As a preliminary I was given four stimulations, two single and two dual; by these few experiences I tried to fix in mind the difference of the two perceptive forms. Then came the series; and it turned out that I was able to judge the two-point impression correctly in 11 out of its 16 appearances. That is a correctness of almost 70 per cent.

The result was encouraging—so much so that I determined to repeat the trial under better conditions. A few days later, then, I worked through the same series with change of order (not that I should have recognized the original order!) and with proper regulation of times and intensities and warning-signals. I now judged the two-point impression correctly in 15 out of 16 cases. Since McDougall's liminal value requires only 13 correct judgments,⁸ my present limen of dual impression, calculated in his way, is something less than zero. I have at least equalled the performance of Meiti and Tapau and Biskak.⁹

I give the series in full, since they are instructive to those familiar with the aesthesiometric experiment.

TRIAL I. PRELIMINARY STIMULATIONS, 4.

Stim.	Jdgt.	Stim.	Jdgt.	Stim.	Jdgt.	Stim.	Jdgt.
2.....2		1.....1		2.....1		1.....2	
1.....1		2.....2		1.....2		2.....2	
1.....2		1.....1		2.....2		2.....1	
2.....2		2.....1		2.....2		2.....1	
2.....2		1.....1		1.....1		2.....1	
2.....2		1.....2		1.....2		1.....1	
1.....2		2.....2		2.....2		2.....2	
1.....2		1.....1		1.....2		1.....1	

Summarizing we have:

2 judged as 2.....11 times
2 judged as 1..... 5 times

1 judged as 1.....8 times
1 judged as 2.....8 times

⁸ R, 190.

⁹ R, 203 f.

TRIAL II. PRELIMINARY STIMULATIONS, 6.

Stim.	Jdgt.	Stim.	Jdgt.	Stim.	Jdgt.	Stim.	Jdgt.
2.....2		2.....2		1.....1		1.....1	
2.....2		2.....2		2.....2		2.....2	
1.....1		2.....1		2.....2		1.....1	
1.....1		1.....1		2.....2		1.....1	
2.....2		2.....2		1.....1		2.....2	
1.....1		1.....2		1.....1		1.....1	
1.....2		2.....2		1.....1		2.....2	
2.....2		1.....1		2.....2		1.....1	

Summarizing we have:

2 judged as 2.....15 times
2 judged as 1..... 1 time

1 judged as 1.....14 times
1 judged as 2..... 2 times

I need not say that there was no hint of duality in the perceptive form which underlay the judgment "two"; I yielded, without compunction, to the stimulus-error. Moreover, since I was interpreting and not describing, I can say very little of the perceptive forms themselves. The one-point impressions were solidly homogeneous, and often had a trace of sting in them; the two-point impressions were duller and coarser, and at times gave a hint of something like granulation. I did not as a rule think of the two-point impressions as larger, more diffuse than the others, though I recall that the one-points with sting were rather definitely small.

The range of McDougall's results might thus be accounted for. We have still to discuss the fact that the average limen of the Murray Islanders is smaller than that of the Englishmen.

Rivers, writing of these same Murray Islanders, lays great stress upon "the over-development of the sensory side of mental life"¹⁰ in the savage. Myers, dealing with a like theme, points out the interpretative character of their sensory interests. "Probably the mode of life led by primitive peoples and their general mental status combine to make them more aware of and attentive to the majority of external stimuli than we ourselves are. . . . A faint odor may be simultaneously perceptible to the civilized and to the uncivilized individual. To the latter it will be full of meaning and so will at once engage his attention; for the opposite reason it is apt to escape the notice of the former." Let us look at McDougall's results in the light of these general statements. The task set to the Murray

¹⁰ R, 44 f., 64.

¹¹ R, 181 f.

Islanders was a task of sensory interpretation; they were not to get a distinct perception of two separate points, but only "a sensation perceptibly different from that yielded by a single point." I have shown that they might have chosen any one of several perceptive forms, and I have argued that different subjects did, as a matter of fact, read different meanings into the instruction given. Their general tendency toward a low limen I ascribe to that sensory interest, that ingrained habit of interpretation of external stimuli, which Rivers and Myers attest. They were to find a "sensation perceptibly different" from another, and they carried the difference—some of them—as low in the scale of separation as 2 mm.

The Englishmen also read different meanings into the instruction given. They were, however, as a group, less interested in the minutiae of external stimuli than the savages; their power of sensory interpretation was less; they paid, we may suppose, more attention to the particular instrument used, and to its probable effect upon the skin. They looked for a sensibly dual impression; and though they did not all confine the judgment "two" to cases in which the stimuli fell apart for perception, yet they naturally tended in that direction. It is very significant that "among the Englishmen were five of the educated class, and these gave a rather higher threshold than the rest, who were all of the lower class."¹² The farther we go from the savage's sensory interest and power of sensory interpretation, the larger do our limens become! Not, of course, that the educated Englishmen were necessarily less sensitive than the rest, but simply that they took "duality of impression" in a stricter sense.

I conclude, then, that we have no right to say "of these Murray men that their sense of touch is twice as delicate as that of Englishmen." That may or may not be the case; but, in any event, the conclusion does not follow from McDougall's experiments. So far as relative "delicacy of tactile discrimination" is concerned, these experiments leave us precisely where we were.

I have tried to find a reasonable explanation of McDougall's results taken at their face value. I have now to express a complete distrust of his formal procedure. The "test" of the Murray Is-

¹² R, 192.

landers—McDougall describes it as "a combination of the method of minimal changes with the method of right and wrong answers"¹²—bears all the earmarks of an incomplete psychophysical method. My criticism, in brief, is that fragments or sections of established methods cannot, without very rigorous trial and definite proof of reliability, be combined to form a new method.

Subjects.	Number of Preliminary Trials.	Separation of Points (Mm.) in Test-series.	Correct Dual Judgments.	Test-limen (Mm.).
1	29	22	5	25?
		24	4	
2	21	40	5	52
		48	3	
		60	9	
		56	10	
		52	10	
		48	7	
		50	4	
		52	8	
3	16	30	4	
		40	7	
		50	9	45
		45	8	
4	12	20	6	
		30 (discarded)	8	
		30	7	25
		25	8	
5	6	30	6	
		40	8	40
6	12	30	8	
		25	7	
		35	7	
		40	10	30?
7	56	—	—	
8	11	30	2	50
		40	4	
		50	8	
9	23	36	9	
		34	8	34
10	21	49	9	
11	10	35 (discarded)	8	48
		35 (discarded)	3	
		40	4	
		50	8	
		60	8	
		80	10	
		70	9	
				50

The aim of McDougall's procedure, on the quantitative side, was to get eight correct dual judgments out of a possible ten. I have before me the data of a careful performance of Whipple's test (1910)

¹² R, 191.

on the "discrimination of dual cutaneous impressions."¹⁴ They have not been published; but by the kindness of my colleague, Professor Kennedy-Fraser, I am allowed to quote from them in this place. The aim of this test also is to "seek a distance such that about 8 correct judgments in 10 are made, *i. e.*, such that double contact is reported as double in 8 of 10 trials." The condensed results from eleven subjects, obtained after the prescribed preliminary practice, are given in the table on page 212.

The subjects of this test received no instruction regarding perceptive form, and the range of the limens (25 to 52 mm.) may be partly due to that omission. If we consider the results solely from the quantitative side, we may draw the following inferences:

1. It is dangerous to repeat a test-series (Subject 2); to repeat is to give the method an opportunity to contradict itself. Conversely, the result comes out most neatly with the use of few test-series and fairly wide steps.

2. Inversions are not uncommon. Subjects 1, 2, 4 and 6 furnish instances in which a lesser separation of the compass-points yields a greater number of correct judgments.

3. The weight to be attached to the preliminary trials is left to the discretion of the experimenter (Subjects 1, 10). The test-procedure thus contains an element of uncertainty.

4. The test as prescribed may break down altogether (Subject 7). The failure in this particular instance is due, not to the inter-currence of paradoxical judgments,¹⁵ but to irregularity of the normal judgments; the subject evidently changed his standard as the trials went on.

¹⁴ G. M. Whipple, "Manual of Mental and Physical Tests," 1910, 207 ff.

¹⁵ This possibility was foreseen by Whipple (*op. cit.*, 211). The discarding of series by the experimenter (Subjects 4 and 11) was done for cause; but it too introduces an element of uncertainty.

To meet the variety of perceptive form, Whipple recommends in his second edition (I., 1914, 247 ff.) a method of contrast. "The threshold may be taken as the distance at which two errors are first made with the ten double points, unless subsequent better records with lesser separations show that these errors were due to a temporary lapse of attention." I am afraid that repetition would still be dangerous; not only attention but also basis of judgment might shift from series to series.

All of these defects are characteristic of an imperfect, incomplete, partial method. It may be said, I think, without qualification that numerical results of the same kind as those obtained by McDougall and by the performers of Whipple's 1910-test may be got by fractionating the results of the method of constant stimuli. Here is an illustration from my own laboratory.

DETERMINATION OF THE TWO-POINT LIMEN BY THE METHOD OF CONSTANT STIMULI.

80 series, 400 observations. Stimuli 0, 6, 12, 18, 24 mm.

(A) Results Arranged in Groups of 10 Series.

Stimuli.	Percentage of Dual Judgments.								Percentage Limits.	Difference.
0	30	10	20	10	0	0	20	20	0-30	30
6	30	80	20	30	30	50	40	20	20-50	30
12	50	50	70	60	40	70	80	50	40-80	40
18	30	90	90	70	80	90	90	50	50-90	40
24	100	100	80	90	100	100	100	80	80-100	20 Av. 32

(B) Results Arranged in Groups of 20 Series.

0	20	15	0	20	0-20	20
6	55	25	40	30	25-55	30
12	50	65	55	65	50-65	15
18	60	80	85	70	60-85	25
24	100	85	100	90	85-100	15 Av. 21

(C) Results Arranged in Groups of 40 Series.

0	17	10	10-17	7
6	40	35	35-40	5
12	57	60	57-60	3
18	70	77	70-77	7
24	92	95	92-95	3 Av. 5

(D) Result of 80 Series.

0	14
6	37
12	59
18	74
24	94

The cases of inversion (4) are printed in italics.

We notice that, as the size of the group increases, the range decreases and the distribution of judgments grows increasingly constant; that is what we should expect. We notice also, however,

that the 8 series of (*A*) are of the order of test-series. If we ascribe them hypothetically to 8 different subjects, we may fix the 8-in-10 limen of the last five as 21, 18, 15, 12 and 24 mm. respectively (range 12-24); no limen can be calculated for the first three. Even, then, if the basis of the test is enlarged, and we take 50 judgments from every one of our supposed 8 subjects; and even if the basis is regularized, and we test all the subjects by the same stimuli; even so, the limen shows a wide range and proves in certain cases to be indeterminable. It is plainly not enough, in this test, to secure eight out of ten right answers by a rapid procedure applied "under the same conditions" to a number of unpractised subjects. For the conditions during such a test are only by chance the same for different persons; the probability is that they are diverse; and the repetition of the test on the same subject may change the original finding. From this point of view, also, McDougall's results are open to grave suspicion.

It is fatally easy for the field-worker and the laboratory-worker to misunderstand each other. So I had better say at once, and emphatically, that I do not want to see the refinements of the home-laboratory carried into the field. When Galton suggested that "in testing the delicacy of the various senses . . . we should do wrong if we pursued the strict methods appropriate to psychophysical investigations,"¹⁶ I take him to have been heartily in the right. I criticize McDougall's combination-method on the formal ground that it is not a method, whether fine or coarse; it is, so far as I can see, essentially the rough equivalent of a section or fragment of the method of constant stimuli; and as a mere fragment of a method it can lead us nowhere. We are fortunate in having the method of constant stimuli in the background, to give us numerical norms; but we cannot use a piece of a method as if it were the whole.

II. COLOR VISION

I have chosen, as a second example, Rivers's work upon color vision. This is a very painstaking bit of research, and its conclusion

¹⁶ F. Galton, "On the Anthropometrical Laboratory," etc., *Journ. Anthropol. Inst.*, February, 1885, p. 4 of offprint.

is stated with becoming caution. The conclusion is "that the color vision of the Papuan is characterized by a certain degree of insensitiveness to blue (and probably green) as compared with that of Europeans."¹⁷ I do not think that the observations made warrant the inference drawn from them; and I therefore take up the cudgels on behalf of the Papuan. To avoid overmuch detail I confine myself strictly to Rivers' report; I deal with the major question of blue, and leave green out of account; and I consider only the observations taken on Murray Island.

The quantitative work was done with Lovibond's tintometer. "The essential part of the instrument consists of three series of colored glasses, red, yellow and blue, very delicately graded so that each forms a series by means of which one passes from a color so faint as to be indistinguishable from colorless glass up to a glass of a high degree of saturation."¹⁸ The results, stated in terms of the unit of the instrument, are as follows:¹⁹

	R.	Y.	B.
17 Murray Islanders.....	17.6 ± 7.66	26.5 ± 9.71	60.0 ± 16.5
18 Englishmen.....	31.7 ± 22.5	20.5 ± 8.11	36.4 ± 15.13

Rivers has excluded from his Murray averages the results found with one boy who probably suffered from "a slight degree of photophobia."²⁰ He includes in the English averages the results of four observers who were "exceptionally insensitive to red" and of two who were "insensitive to blue."²¹ If we ourselves exclude these cases, we get the revised figures:

Englishmen (14) 18.0 ± 5.5 (18) 20.5 ± 8.11 (16) 34.1 ± 13.66

The exclusion of the defective subjects brings the averages into closer accordance with Rivers' theory; and for that very reason he

¹⁷ R, 94.

¹⁸ R, 70 f. Various forms and uses of the tintometer are discussed by J. W. Lovibond, "Measurement of Light and Color Sensations," 1893. I am not familiar with the instrument, and Lovibond's description is, unfortunately, not always full. The yellow glasses "have a distinctly greenish tinge" and the red glasses are "distinctly bluish" (R, 71, 74 f.).

¹⁹ R, 72.

²⁰ R, 73.

²¹ R, 73.

may have thought it fairer to leave them in. The Murray Islanders and the Englishmen now agree as regards red and yellow; both the liminal values and their mean variations are of the same order; but they differ markedly as regards blue.

On this point I have two remarks to offer. (1) In experiments which I have made with Hering's colored glasses, my observers have reported that it is difficult to determine the chromatic limen of R and B (I have had no such report for Y), because the faintly colored glass shows, at the moment of exposure, a flush or wave of color which immediately disappears through adaptation. It is possible that the four English observers who were "exceptionally insensitive to red" failed to notice this momentary flush in the neighborhood of the limen, while the other Englishmen and the Murray Islanders (whom we know to be keenly interested in red) noticed it and placed the limen accordingly. The range of results for the Murray Islanders is 40 to 5; the range for the 14 Englishmen is 40 to 10: a remarkably close agreement. In the case of blue, it is possible that the 16 English observers noticed the flush and reported it as color, while the Murray Islanders (who are definitely uninterested in blue, since they have in their surroundings no blue object of reverence or utility) disregarded it. The range for the Murray Islanders is 100 to 30, and that for the 16 Englishmen 80 to 15; the ranges are thus of the same order of magnitude, are very large, and show a wide overlap. My distinction, therefore, must not be pressed; the possibility is rather that the Murray men *tended* to overlook the flush, the Englishmen to report it as blue. In the case of yellow (for which, as it happens, I have no report of the flush) the ranges are 50 to 10 for the Murray Islanders and 60 to 4 for the 18 Englishmen. The agreement is less striking than for red, but is still fairly close.

There is, then, a possibility that the difference in the case of blue may be due, in part at least, to regard or disregard of the supraliminal flush of color to which I have called attention. I have myself had student-observers who disregarded the flush, both of R and of B, because they thought the field should look colored during the

whole period of observation.²² There is, however, a second possibility, to which I now turn.

(2) Geissler, working upon the chromatic limen with colored papers, found that increase of the general illumination markedly decreased the limen of B, while it had no such marked effect upon the limens of R and Y. I am not quite sure of the figures which should be quoted for comparison; but it appears that, for two observers, increased illumination (natural daylight "several times as bright" as the artificial daylight otherwise used) lowered the limen of B, in degrees of the color disc,

	from 4.12 or 4.64	to 1.83,
and	from 5.28 or 5.80	to 2.96.

Whichever pair of larger figures we take, as a basis of comparison, "the striking fact is that the limen for blue in natural light was lowered."²³ I can parallel this result by observations on colored glasses. In 1890 I visited with Mr. (later Sir Francis) Galton the anthropometrical laboratory which he had equipped at South Kensington; and among other things I worked awhile with Galton's "instrument for testing the perception of differences of tint."²⁴ My notes tell me that the laboratory attendant and I "made a great hash" of our trials with blue, and that Galton remarked on the gloom of the laboratory as unfavorable to color work. I cannot remember that we worked

²² The tintometer limens for the four red-insensitives are 50, 70, 80, 120. Rivers thinks that the subjects with the two highest limens "had probably some degree of weakness of the red-green sense" (R, 73), and they may belong to Nagel's anomalous or atypical trichromates (W. Nagel, "Ueber typische und atypische Farbensinnsstörungen," *Zts. f. Sinnesphysiol.*, XLIII, 1908, 299 ff.). The two blue-insensitives have limens of 50 and 60; other subjects, not characterized as insensitive to blue, give 45, 60, 60, 80. These high limens may be due simply to lack of practice; experience in the laboratory shows that undergraduates are far more likely to give the name "gray" to a slightly bluish gray than to a red-gray or a yellow-gray of the same chroma; blue is undoubtedly like gray. These considerations modify my argument in detail; they do not affect its principle.

²³ L. R. Geissler, "Experiments on Color Saturation," *Amer. Journ. Psych.*, XXIV., 1913, 177 f.

²⁴ F. Galton, "Exhibition of Instruments," etc., *Journ. Anthropol. Inst.*, August, 1889, 27 f.

with glasses of other colors; perhaps we did; the thing that struck me, at any rate, was the difficulty of distinguishing blues in a darkish room. Recent work with Hering's colored glasses shows that a shift of the instrument employed, on a gray snowy day, from the window to the middle of a large, gray-painted room produces the following changes in liminal values (three observers; method of limits; conventional units):

Obs.	Light.			Dark.		
	B.	Y.	R.	B.	Y.	R.
I....	36.0	48.5	59.75	68.5	54.5	83.5
II....	26.75	32.0	45.75	41.25	42.5	51.0
III....	42.2	47.0	43.0	59.2	68.6	78.4

I give no further details, since I attach little importance to the numerical values; however carefully the work is done, it is full of errors. I notice only that B is the one color that suffers consistently in the dark, and that it suffers on the average much more than Y and about as much as R. The figures are:

INCREASE OF LIMEN IN DARK.

Obs.	B.	Y.	R.
I.....	32.5	6.0	23.75
II.....	14.5	10.0	5.25
III.....	19.5	21.6	35.4
Average.....	22.1	12.5	21.5

If, now, the tintometer in Torres Straits was set up in a room of "the disused missionary house," and in England in a well-lighted laboratory room—we are not informed as to the English conditions—then we may be pretty sure that the Murray Islanders were at a disadvantage on the score of blue. That conclusion follows both from Geissler's results and from my own. Such a disadvantage, whether acting alone or combined with a tendency to disregard the supra-liminal flush, might account for the difference in the average limens of Murray men and Englishmen. It may be that the Murray Island limen for Y (slightly higher than the English, despite its somewhat

closer range) is due to the same difference of general illumination. We are then, it is true, left at loose ends in the matter of R. Here, if comparison is at all permissible, Geissler's results are in agreement with Rivers'; my own are in disagreement. But we do not know whether the two R glasses were alike. Above all, I cannot tell whether the tintometer-series of colored glasses are so combined with grays as to show the same "brightness" throughout, or whether during an experiment they brighten with decrease of chroma; I cannot tell, either, whether the colorless field, with which the colored field is compared, itself varies with the "brightness" of the colored glasses or remains the same for all.²⁵ In my own experiments "brightness" varied with chroma, but the colored and colorless fields were of approximately the same "brightness" in every observation. Here are possible differences of procedure that might affect the results.

I said just now that we are not informed of the conditions under which the English tests were made. It is worth noting, however, that Rivers found excessively high limens "in testing Europeans in too strong a light."²⁶ Since too strong a light (daylight) could hardly be obtained save in a specially lighted laboratory room, it seems probable that my supposition as regards the placing of the tintometer is correct.

All of these criticisms are offered, of course, with the greatest reserve; Rivers may be able to meet them point for point. Taking his report as it stands, I think they are sufficient to cast serious doubt upon the conclusion which he draws from the tintometer-results. The report, however, is incomplete; we lack details of experimental procedure and conditions; and the English observers, who

²⁵ Lovibond speaks of neutral-tint glasses, standards, units; he also has diffusive glasses, thin slips of ground glass (*op. cit.*, 21, 31 ff., 48, 101 f.). It would therefore seem possible to keep hue and "brightness" of the colored glasses constant while chroma varied, and to equalize the "brightness" of the colored and colorless fields. Rivers does not tell us whether this was done. In setting up the instrument for differential determinations, he found that the "difference in brightness" of the glasses rendered the results inconclusive (R, 74). If brightness affected these results, must it not have affected the others? and if it was compensated in the other experiments, might it not have been compensated in these?

²⁶ R, 73.

might have been thoroughly tested, are characterized only in round terms. The instrument employed may have been the best available; it embodies a vast deal of patient labor; but it has not made its way into our laboratories, and it has not (so far as I know) received a thorough trial in any laboratory. We have no proof that it is adequate to a comparative testing of color vision.

I pass to the vexed question of color nomenclature. On Murray Island "there was great definiteness and unanimity in the nomenclature for red, rather less so for orange and yellow, less so for green, and very great indefiniteness for blue and violet."²⁷ "In Murray Island there is no proper native term used for blue. Some of the natives, especially the older men, use *golegole*, which means black [cuttle fish], but the great majority use a term [*bulubulu*] borrowed from English and modified so as to resemble the other members of their color vocabulary [the color names are formed by reduplication from the names of various natural objects]. Another word, *suseri-suseri* [rainbow], is used occasionally for blue and also for green, and in the absence of the borrowed word this might have been used more often."²⁸

The absence of a word for blue, if the fact stood alone, is no argument against sensitivity to blue. For the savage names only what interests him, and we have seen that his interest is directed upon the interpretation of sensory stimuli. But there is in Murray Island no such sensory stimulus, no object of daily use or interest—no pigment, for instance—of a blue color. I think that Rivers would not dispute this position, if the fact stood alone. It is only because of other facts, and because the character and distribution of the other color-terms in the vocabulary arouse suspicion, that he would argue—always tentatively—from "defective color language" to "defective color sense." We must therefore get a conspectus of the vocabulary at large.

I have arranged the data for Murray Island in the form of a table.²⁹ Above stand the names of the objects from which the color

²⁷ R, 54 f.

²⁸ R, 66 f.

²⁹ From R, 53 ff.

names are derived. The colors are indicated by their initials (R, red; I, indigo; etc.). A capital letter means that the color was designated by the name of the object at the head of its column in the majority of cases, or (for Y, I and V) by considerable groups of the subjects; a small letter means that the color was so designated less often, sometimes by a single subject. Rivers has, unfortunately, not stated these results in numerical form. A + or — sign after a letter means that the color name was modified by "big" or "little"; thus, o— means that orange was called "little blood-blood" by a few subjects; p+ means that purple was called "big blood-blood" by (as it happens) one man.

Blood.	Red Ochre.	Turneric.	Yellow Ochre.	Zow Flower.	Bright.	Turneric + Cuttle-fish.	Sea + Pus.	Turtle Gall-bladder.	Newborn Child.	Pus.	Leaf.	Rainbow.	English "Blue."	Cuttle-fish.	Sea + Cuttle-fish.	Dull.	Blue + Cuttle-fish.	Rainbow + Cuttle-fish.	Dark.	Secretion of a Mollusc.	A Mollusc + Blood.	Somer Fruit + Blood.
R, R+, r— o, o—	o	O Y	o Y g— bg—	y	y	yg	yg	YG G bg b	y yg g bg b	yg g bg b	yg g bg b	yg g BG b i v	B I	b I V i	b v	b V	v	v	v	p	p	p
v— P—, p+																						

I have included in the table all but two of the color names employed. BG was called "dirty yellow-ochre" as well as "little yellow-ochre"; I have not thought it worth while to make a separate column for this compound form. V was called blood-white, if *kakekakek* means white; I return to this case presently.

Let us now look at the distribution of the color-names, taking the column of the table as unit. Then

R has 1 name
 O has 4 names
 Y has 5
 YG has 7
 G has 6
 BG has 6
 B has 8 (or 7 if "blue" is excluded)
 I has 4 (or 3 if "blue" is excluded)
 V has 8 (or 9 if "blood-white" is included)
 P has 4

Rivers' phrases are:

- "great definiteness and unanimity for R" (1 name)
 "rather less so for O and Y" (4 and 5 names)
 "less so for G" (6 names)
 "very great indefiniteness for B and V" (8 and 8 or 9 names)

The rise from 5 to 8 thus changes a "rather less great definiteness and unanimity" to "very great indefiniteness." Yet the B names group, clearly enough, with the YG, G and BG names. We need, as I said above, the actual numbers of subjects who used particular terms; then we could weight the data of the table.

Rivers' further findings³⁰ are as follows:

White paper is called	<i>KAKEKAKEK, zaserzaser, lime.</i>
Deep black paper	<i>CUTTLE, BIG CUTTLE, kukikuki.</i>
Dull black paper	<i>CUTTLE, LITTLE CUTTLE, ashes-cuttle, ashes, gray clay, New Guinea earth, dirty.</i>
Gray (162° W + 198° Bk) ³¹	<i>kakekakek, little kakekakek, ashes-kakekakek, ashes-zaserzaser.</i>
Gray (49° W + 311° Bk) ³¹	<i>ashes, gray clay, cuttle.</i>
Holmgren's pale green test wool	<i>kakekakek, ashes, little turmeric, zaserzaser, zom-flower.</i>
Violet test wool	<i>ashes, kakekakek, zaserzaser, little blood, cuttle.</i>
Brown wools are called	<i>little blood, little turmeric, ashes, cuttle, dull, "according to their prevailing tone and shade."</i>
Slightly saturated colors and dull black are called	<i>dudu.</i>
Color of native skin	<i>cuttle.</i>
Dark colors	<i>kupekupe.</i>
Dark	<i>kupekupe, kukikuki, kakerikakeri.</i>
Bright, glittering	<i>zoromsorom.</i>

The cruces of the vocabulary are *kakekakek* and *cuttle*. Rivers translates *kakekakek* roundly by white; he does not know the derivation of the word.³² We find it applied to white paper, light gray paper, Holmgren's apple-green test wool, the violet test wool, and

³⁰ R, 54.

³¹ We are not told whether these grays were mixed from the dull black or the deep black paper.

³² R, 49, 56.

(in the form blood-*kakekakek*) to violet paper.³³ I suggest that it is the equivalent, on the side of light, to *dudu* on the side of dark; that is, that it means "light and inconspicuously colored." If I were guessing at its derivation I should expect to find that the object *kakek* is something of use and interest which is not easily found by reason of its lightish, faded or washed-out color. The term "blood-white" for violet would then be practically the same as the "little-blood" already entered in my table.

Cuttle is applied to black paper, dark gray paper, brown wool, native skin, blue paper, indigo paper, and violet paper and test wool. Rivers translates the word by black; he notes that the older men use it for blue, and remarks on the fact that "intelligent natives should regard it as perfectly natural to apply the same name to the brilliant blue of sky and sea which they give to the deepest black."³⁴ The thing is strange to us: but we must consider the native. In the first place, we do not know whether the derivation of the word is present to the native's mind. Rivers thinks that "newborn child color" may simply mean "light";³⁵ I suppose that the specific reference to the skin-color of the newly born has dropped away. Cuttle-color, in the same way—especially since the word is an old one—may have a general and not a specific meaning. What, then, in the second place, may this meaning be? Rivers seems to derive it from the inky secretion of the animal. But the word *gole* means, not cuttle ink, but cuttlefish; and it is characteristic of these animals that they change color, chameleonwise, to suit the color of their surroundings.³⁶ May it not be that the thought in the native's mind, when he uses the word *gole*, is "can't find him," "can't see him"? (The chief of Muralug called black by a word which another native translated as "No, can't see him."³⁷) And if this is the case, is it not natural

³³ The "violet test-wool" is apparently the relatively unsaturated violet that Rivers used in his experiments on color-matching (R, 49).

³⁴ R, 55, 56, 66, 94.

³⁵ R, 55, 56.

³⁶ R. Lydekker, "The New Natural History," VI., 327. The inky discharge of the cuttle fish is also regarded as a "defensive reaction"; and "cuttle ink" as well as "cuttle-fish" might suggest the thought "hard to find."

³⁷ R, 59.

that the adjective *golegole* should be applied to any large expanse within which no discriminable features can be made out? The dark of night, the skin of the body, the expanse of sea and sky, these are precisely the things to which a term meaning "uniform," "even," "undifferentiated," is suitable. Then, of course, when the native is asked to characterize black, blue, brown, violet papers or wools,—a wholly novel task,—he gives them the name that he has ascribed to the color-expanses, the large even color-fields; he calls them all *golegole*. On this hypothesis, we may pair *golegole* with *warowar*,³⁸ just as we paired *kakekakek* with *dudu*; for *warowar* is used of marked, patterned, particolored fields, as I have assumed *golegole* to be used of undifferentiated expanses.

Guesswork! the objector will reply. Guesswork, no doubt; but a guess that is suggested directly by the reading of Rivers' text. The Murray Islanders have, for instance—my table shows it—a color name derived from the secretion of the purple-yielding mollusc, and another derived from the name of the mollusc itself. The Western Tribe has, apparently, only one word, derived from the name of the mollusc; the same tribe has a term for dark brown derived from *saingui*, ink of cuttlefish, but no color name derived from the cuttlefish itself.³⁹ So far, then, as my data go, it is not fanciful to argue that *gole*, meaning cuttlefish, does not necessarily carry the meaning of inky black.

Even, however, if this particular guess is wrong, the argument on behalf of the Murray men is still not at an end. I see no reason why they should be interested in the "brilliant blue of sky and sea"; for the brilliant blue means fine weather and calm. One or two individuals of the Western Tribe called orange by a word meaning sunrise, and violet by a word meaning a cloud which is black on the one side and *kiaur* [violet?] on the other; there is no reference to blue sky.⁴⁰ The chief of Muralug called YG sea-color, G "like another kind of sea, another wind," and B "sea with another kind of

³⁸ R, 55.

³⁹ R, 56, 60.

⁴⁰ R, 61.

wind, plenty blow";⁴¹ the inference is plain. I cannot here take the space to analyze these other vocabularies; I have chosen that of Murray Island as the most favorable to Rivers' hypothesis of defective blue-vision. But I point out that the case against that hypothesis does not stand and fall with my interpretation of *golegole*.

The subject of color nomenclature may be approached from another angle. No one can read the Murray Island terms without wondering what a group of civilized persons would make of colored papers, if they were required to give them the names of concrete objects. I thought it worth while to make an experiment on the matter. I cut two-inch squares from three of the Milton Bradley series, the spectral colors, the tints No. 1, and the shades No. 1; 54 colors in all. These were mixed in haphazard order, and were shown to 5 observers, two women and three men. The instruction ran: "You are to name these colors by first impression as soon as shown. Use no abstract color names, but use always the name of some concrete object that the color suggests to you. You may also use the words, Dull, Dark, Bright, Light, if the stimuli impress you in that way, without seeking any specific color name." I included these four terms because the Murray Islanders used words of the same significance. The experiment went smoothly in a period of some 20 minutes; the only modification of procedure was that, if an observer gave "sky" for blue, I called for a second concrete name. "Sky," as I have shown, was foreign to the Murray Island vocabulary. I subjoin the results for all colors in which blue was involved.

I have italicized the terms Dull, Dark, Bright, Light. In the whole series of 270 namings, these words were used 64 times (I exclude the cases in which Sky was changed to Light, though I regard these as significant). In the 120 cases of what we may call the blue-range, quoted above, the words occur 43 times. The general percentage is thus 23.7, the percentage for the blue-range is 35.8. If we take simply the three blues (GB, B, VB), the percentage is 35.5 (or, if the "Sky-Lights" are included, 42.2). Were then my

⁴¹ R, 59. "These instances," says Rivers, "illustrate very well the liking of these people for similes." They seem rather to show the direction of practical interest.

observers "insensitive to blue"? Not a bit of it: their color-vision, by the regular laboratory tests, is normal.

TINTS No. 1.

Obs.	BG.	GB.	B.	VB.	BV.	V.	RV.	VR.
1 (f.)	[sky] <i>light</i>	[sky] <i>light</i>	<i>bright</i>	violet	hyacinth	violet	<i>light</i>	<i>light</i>
2 (f.)	robin's egg	small girls [frocks]	[sky] skies badly painted a dress	amethyst ring	handker- chief border	ribbon	a per- fume	orchid
3 (m.)	robin's egg	water		<i>light</i>	<i>light</i>	a gown	<i>light</i>	violet
4 (m.)	faded grass	[sky] <i>light</i>	[sky] <i>light</i>	<i>dull</i>	<i>dull</i>	<i>dull</i>	<i>dull</i>	<i>light</i>
5 (m.)	robin's egg	robin's egg	a wagon	<i>dull</i>	<i>dull</i>	hat- ribbon	<i>light</i>	violet

SPECTRAL COLORS.

1 (f.)	tur- quoise	<i>bright</i>	<i>bright</i>	ink	violet	violet	violet	<i>dark</i>
2 (f.)	china	Japanese porcelain	<i>bright</i>	aniline dye	poodle	a smart furniture shop	a maga- zine	books
3 (m.)	grass	water	[sky] back- ground of picture	a dress	a blacked eye	peacock	<i>light, dull</i>	<i>dark</i>
4 (m.)	<i>light</i>	wall- paper	[sky] Japanese stamp	[sky] Japanese stamp	a dress	<i>dark</i>	<i>dull</i>	photo- graphic paper
5 (m.)	verdigris	<i>dull</i>	lake- water	ink	violet	violet	violet	<i>dull</i>

SHADES No. 1.

1 (f.)	<i>dull</i>	<i>dark</i>	a dress	<i>dark</i>	ink	violet	<i>dark</i>	<i>dark</i>
2 (f.)	?	Van- tine's shop	linen hang- ings	blotting pad	marking pencil	?	?	Alice in Wonder- land [cover]
3 (m.)	dark trees	bluejay	baseball	<i>dark</i>	necktie	<i>dull</i>	grape- juice	grapes
4 (m.)	wall- paper	<i>dark</i>	<i>dark</i>	<i>dark</i>	sunset	<i>dull</i>	<i>dark</i>	?
5 (m.)	curtains	<i>dull</i>	?	<i>dull</i>	<i>dull</i>	violet	<i>dull</i>	<i>dark</i>

The question-marks mean that no judgment was given in the sense of the instructions; the observer said "thick like velvet," or "pleasant," or "ugly," or "dignified," or "thought of color-theories."

We cannot hope, of course, to invert this experiment; we cannot expect, if we ask for names of R, Y, G and B objects, to find a greater scattering in the B-list than in the others. For blue flowers, blue articles of dress, blue hangings and blue china and other household gear are common enough; and experiment shows that blue sky and green grass are more often associated than are red and yellow to any object of their color.⁴² We live in a world where blue has its acknowledged place. The Murray Islander does not. Blood he knows, and red and yellow ochre, and turmeric, and the brilliant deep-green gall-bladder of the turtle—all of them objects of the highest importance in the conduct of his life; but blue he has no dealings with. "Every detail of the behavior of the natives in connection with the naming of color was consistent with the idea," Rivers says, "that blue was to them a darker or a duller color than it is to us."⁴³ I submit that their behavior is equally consistent with the idea that blue did not interest them.

Not much need be said of Rivers' work on the matching of wools. "The natives," we are told, "understood what they were required to do very readily in most cases."⁴⁴ Rivers does not himself inform us what this requirement was; but it was evidently the matching of wools for hue (color tone). The lack of any explicit statement to this effect is, I think, significant. We are so accustomed to classify colored objects by their hue, their "color" proper, that the classification seems to us to be natural and normal. The Murray Islander, however, appears to classify by total impression; the wools appeal to him by their combined hue, tint and chroma; and

⁴² I asked the 19 students who happened to be in my laboratory at the time (8 women and 11 men) to write down the names of the first five R, Y, G and B objects that occurred to them. The order was varied, so that any practice-effect might be roughly compensated. Green grass came 17 times, blue sky 15 times, and red blood only 8 times, out of the possible 19. The B objects fell into the same rough groups as the others (person, personal adornment; clothing; articles of personal use;—house, household furniture;—vegetation, flowers, fruit; beasts, birds, insects;—landscape and seascape).

⁴³ R, 94. I am glad to find myself, on this point, in substantial accord with R. S. Woodworth ("The Puzzle of Color Vocabularies," *Psych. Bull.*, VII., 1910, 329 ff.).

⁴⁴ R, 49.

now one of these moments and now another may be the basis of his judgment. "One could often hear a native saying *kakekakek* to himself as he picked up a colorless wool to place with the green," *i. e.*, with Holmgren's apple-green test wool.⁴⁵ Rivers regards the "natural tendency to put together all the wools to which the same name was given" as a fallacy of nomenclature.⁴⁶ It looks rather as if the native varied the basis of his comparison from hue to tint and chroma. For "the same name" is not applied to different colors without a reason.

The actual "matches" are as follows:⁴⁷

Test Wool.	Matched Wools.
Holmgren's red	reds, saturated pinks.
Bright green	greens, often blue-greens, occasionally almost pure blues.
Holmgren's purple	"very readily matched by all, though the majority refused to take pink wools if much less saturated."
Holmgren's apple green	"matched correctly by the majority," often "with bluish or violet wools of about the same saturation," by 7 with "neutral wools with a faint pinkish tinge."
Yellow	"matched correctly by nearly all," by 2 men and 5 children with reddish wools, by 1 man and 3 boys with blue wools.
Blue	matched by 27 (out of 107) "with violet as well as with blue or bluish green wools," by 1 man with an almost colorless wool, by 1 man with a brown and with a yellow wool.
Violet	"matched or compared by 12 with neutral wools and by 14 with distinctly reddish or pinkish wools," by 1 boy with a brown wool, and by the chief (who called all <i>kakekakek</i>) with a B and a G wool of about the same saturation.

The only facts that claim particular attention, after our foregoing study of the color vocabulary, are (1) the confusion of yellow with

⁴⁵ R, 49.

⁴⁶ R, 49 f., 93. Here is a chance for the obverse fallacy: my observer 2 (f.) gives *marking-pencil* for BV Shade 1 and for Spectral OR. We happen to know that examiners use differently-colored pencils; but suppose that the vocabulary was strange to us, and that we found the same object called BV and OR!

⁴⁷ R, 50.

blue by a man and three boys; and (2) the confusion of blue with yellow by one man. The boys are ruled out by Rivers on the ground of carelessness; the men remain. Rivers, however, gives us the clue to their behavior: "the yellow test wool used by me was a dull yellow," and blue is also regarded by the natives as a dull color. If the men muttered or thought *akòsakòs* as they matched or compared all is in order.⁴⁸ My observer 5(m.) gives the name "dull" to the "shades" of YO, Y, GB and VB.

I said just now that we are accustomed to classify colored objects by their hue; the following experiment shows that we can classify them, without trouble, by other means. I showed the 125 wools of the standard Holmgren set to my colleagues Drs. Boring, Foster and Weld, with the following request: "Arrange these wools into groups of similars, on the basis of first impression. Do not set out to judge by hue or tint or chroma; do not try to maintain any uniform basis of judgment; group the wools simply by the first impression they make upon you." I had recourse to highly experienced observers, because I thought that they would be less biased in favor of hue than undergraduate or graduate students; I thought also that they would be less afraid of making "foolish" matches. The result of the test is that Boring distinguishes 9 groups, Foster 18, Weld 4. Hue has a marked influence on choices: but Boring, who shows this influence most strongly, still throws together R, O, P, V, and in another group Y, G, BG, V; Foster groups with the Holmgren test-purple R, G, BG, B, P and V wools; and Weld groups with the same test wool R, O, Y, G, BG, P and V wools. This is a single test, to be sure, and the same observers would probably have made different groups had it been repeated. The fact remains, nevertheless, that if the prejudice in favor of hue is weakened or removed an expert observer will find likenesses of color-impression at least as wide-ranging as those of the Murray people.

It has not seemed necessary to enter in detail upon other tests than those conducted on Murray Island; and it does not seem necessary to discuss here the remaining tests of contrast, after-images, etc. I find in them nothing to invalidate what has been said above.

⁴⁸ R, 50 f., 55 f.

Let us now see what can be urged on behalf of the blue-vision of the islanders.

1. Within the period of a generation, "the great majority" of the Murray Islanders have learned to use the modified English word *bulubulu* for blue colors. In the tintometer experiments, "owing to the fact that *bulubulu* had become the general term for blue, there was no indefiniteness in the naming of this color"; and in the work on contrast the subjects "were all in the habit of calling blue *bulubulu* when talking to me."⁴⁹ This ready adoption of a foreign term seems to indicate that the natives could distinguish blues when once their interest and attention had been directed toward them.

2. In testing Europeans with the tintometer, Rivers found that oftentimes "the subjective contrast color was seen when the objective color failed to be recognized." On Murray Island this phenomenon was rare. "In many hundred observations, a color was only stated to be on the wrong side 15 times. No less than 6 of these occurred with a B glass when the opposite aperture was called *bam-bam* [turmeric]; in one case the opposite aperture was called R. The aperture opposite the R glass was called *bulubulu* 4 times and *giazgiaz* [newborn child, light] once; opposite a Y glass, B was seen twice and R once. Some of these were no doubt accidental, but it is interesting that the instance which occurred most often was when the objective color was B, to which they seemed so insensitive."⁵⁰ It is equally interesting that the Y glass gives a B contrast twice out of three times; and the contrast-R may be justified for a greenish yellow glass shown in poor illumination. Moreover, the R glass was a carmine, and the complementary of carmine is BG. The report of *bulubulu* four times out of five (though *giazgiaz* is itself an occasional word for blue) does not look like insensitivity.

3. In the test of negative after-images "R was most readily seen and B was doubtful."⁵¹ But the stimuli were zigzags of colored

⁴⁹ R, vi., 2, 66, 71, 80 f.

⁵⁰ R, 81. The anomalous reds (if both are anomalous) may be compared with the anomalous light violet or purple (for me the color is definitely a purple) which workers in my laboratory have found even under achromatic adaptation; see L. M. Day, "The Effect of Illumination on Peripheral Vision," *Amer. Journ. Psych.*, XXIII., 1912, 573; and cf. the anomalous peripheral pinks or purples of R, 78.

⁵¹ R, 82.

paper shown for 10 to 20 sec. on a gray ground, or of gray paper on a colored ground; and in what illumination? The method favors R; I can reproduce the results with observers of normal vision. There is nothing to show that the Murray men were not the victims of circumstances; and Rivers does not report corresponding tests of Europeans.

4. Rivers lays no great stress on his observations of color-preference. "Among saturated colors," however, "R easily had the first place, followed by B, while Y and G were distinctly less favored. . . . Complementary colors were commonly worn together, Y with B and G with R."⁵² The first of these facts is a little surprising, in view of the practical importance of yellow and green;⁵³ taken together with the second, it may perhaps indicate that the natives, once their attention has been called to color as such, have a normal appreciation of blue.

Here, however, we are dealing with fairly large surfaces of color, surfaces that would be viewed in indirect as well as in direct vision. One of Rivers' strongest points against the native is that, peripherally, "the color blue was recognized readily, even more readily than other colors. The color of the patch used was saturated,"⁵⁴ but even so the results do not accord with those obtained in direct vision, so that the two sets of observations need to be reconciled. I have tried to show that the tests of direct vision are not convincing. It seems, also, that Rivers' argument from the sensitivity of the

⁵² R, 84.

⁵³ I have said nothing of the supposed relative insensitiveness of the islanders to G, partly for reasons of space, partly because the position of B is the more important. H. E. Houston and W. W. Washburn ("On the Naming of Colors," *Amer. Journ. Psych.*, XVIII, 1907, 523) found no overlap of B and Y or R and G, but a marked confusion of B with G and B with P. It is noteworthy that H. K. Wolfe ("On the Color-Vocabulary of Children," *University of Nebraska Studies*, I, 1890, 23) finds no such confusion of B and G. Many points of Wolfe's investigation are of interest in connection with the Murray Island results. Thus "the pupils seem loth to confess their ignorance; four fifths of them attempted to name orange, and only one fifth knew what it was" (24); and the expressions "dark white" and "light dark" were used in good faith and with meaning (28).

⁵⁴ R, 79. If the tests were made in the order in which they are reported (cf. R, 49, 53, 70) the name *bulubulu* may have become standardized simply by the progress of the tests themselves.

peripheral retina proves too much. For if, by the aid of indirect vision, large expanses are better seen and more readily named than small patches of color, how is it that the brilliant blue stretches of sea and sky are still called *golegole* by subjects whose attention has been called to their color? And how is it that the blue of the rainbow is called *golegole*?⁵⁵

On behalf of the Papuan, then, let so much have been said. I am not in the least concerned, in the present paper, with his macular pigmentation; that is another story. I am concerned only with the adequacy of Rivers' tests to various problems of sense-psychology. The tests appear to me to be inadequate. If Rivers can meet my objections, he must at any rate go beyond the limits of his printed report, and I shall have done some service in bringing out further observations and further arguments.

III. GENERAL REMARKS.

What, now, are the requirements of a field-test? It should set the subject a task which is both simple and definite; it should be capable of performance in a relatively short time and with apparatus that is strong, portable and relatively cheap; it should be laid out so simply that its conduct is easily mastered and so definitely that there can be no variation in its procedure; and it should yield results that are directly relevant to the object of the test, are expressible in numbers and thus are intercomparable. These, in general terms, are the requirements: how shall we go to work to meet them?

We must realize, first of all, that the test is not a laboratory experiment; we must set ourselves at a certain remove from the laboratory; and especially we must avoid misleading analogies drawn from laboratory technique. I have pointed out that McDougall offers his æsthesiometric method as a combination of the methods of minimal changes and right and wrong cases; and I daresay that this title gives the method a sort of *cachet* in the minds of many readers; it may have had a reassuring influence upon McDougall himself. Rivers makes, I think a like mistake in his introductory discussion.

⁵⁵ R, 69 f. The good observer who described the rainbow from memory as red, white and black probably used the terms *kakekakek* and *golegole*, so that the description might be interpreted as red, faded-looking, blue.

"I believe," he writes, "that the smallness of the mean variation in most of the quantitative investigations will convince those acquainted with the procedure of experimental psychology of the trustworthiness of the observations."⁵⁶ But what is the procedure of experimental psychology? A set of instructions, carefully formulated and intelligently grasped; an instrument of precision; a large number of observations, made in accordance with a prescribed method and sufficient for mathematical treatment; a variation of conditions to throw this or that aspect of the subject-matter into high relief; experiments distributed regularly over months or years. Under such circumstances, truly, the *m. v.* may be an index of steadiness of attention or of general attitude. Not by any means necessarily under other circumstances! For a small *m. v.* may mean that the subject has over-simplified his instructions, and is performing an easier task than the task set him; or that he has discovered some secondary criterion of judgment, some short cut to response, and is not performing his allotted task at all. Or a small *m. v.* may mean that the unit of the instrument is too large, and that the performance of the task is thus artificially regularized. In these cases uniformity of result would spell laziness, or perverted ingenuity, or too gross a graduation of stimuli; in other and more extreme cases it might be due to fatigue or to motor habit. We cannot argue directly from laboratory-experiment to field-test.

Secondly, however, we must make full use of the laboratory. I suppose that most laboratories possess records of practice-work done by undergraduate students according to the schemata of the principal psychophysical methods; I have quoted a record of this sort, a determination of the two-point limen by the method of constant stimuli. Such records are not worth publishing, but they are worth preserving.⁵⁷ They furnish norms of the performance of comparatively un-

⁵⁶ R, 4.

⁵⁷ It is important to preserve not only the numerical values of the limen and of the measure of precision but also the rough data of the whole experiment. If the students are supplied with two cross-section forms and a carbon paper the duplicate may easily be obtained.

The rough data of the field-tests should also be accessible; all through this paper I have felt the need of further detail. I should think that sales to laboratories could be assured beforehand, enough to cover the cost of mimeographing the complete records.

practised observers, and they thus provide a ready means of testing any abbreviated test-method that may be proposed. Is it enough to take 10 observations of a kind, and has the 8-in-10 limen any definite significance?⁵⁸ Is it enough to take 5 observations, and has a 4-in-5 limen any value? These are questions not of pure but of applied mathematics; they can be answered only in the light of comparative data; and the control-data are ready to hand in the laboratories. It is useless to make tests in the field, and to repeat them later upon civilized subjects, until we know whether the test-procedures are themselves methodically reliable. So the laboratory may help on the score of method. It may also help in other ways; our discussion of the perceptive forms in aesthesiometry applies, *mutatis mutandis*, to more than one of the Torres Straits experiments. The analyses of the laboratory show what the tests are really doing, what psychological level has been reached. The test of an optical illusion, for example, may tell us nothing of the relative magnitude of the illusion in the case of savage and civilized subjects, but may nevertheless bring out the psychologically important fact that savage and civilized approach the particular task set them in different ways, or come to it in different attitudes of mind.

I am not inviting the field-worker to fall between two stools; I am rather pleading for coöperation. The field-worker seeks to obtain psychological data which shall enable him to rank a primitive race in relation to the various strata of his own civilized community. He knows, in a rough way, what can be done with a primitive population; the home-staying psychologist does not. The laboratory-worker, on his side, knows that a good many of the tests commonly employed are scientifically worthless; yet he cannot be continually playing the critic. Is it not a clear case for coöperation? So far as I know, we have to-day no approved æsthesiometric test that can be carried into the field. No: but if we settled, plainly and positively, what it is that we want the test to tell us; and if the field-worker kept guard over complexity of technique and the laboratory-worker over sources of error; then a test would be forthcoming.

⁵⁸ As regards the æsthesiometric test I have answered this question in the negative. My own first series with the apposed compass-points gives runs of 10 consecutive dual impressions with 80 per cent. correct judgments. Unfortunately the whole run was not 10 but 16.

In conclusion I offer a tentative suggestion as regards the general conduct of field-tests; it is always dangerous to be positive, but I take the risk. There is, I understand, a present tendency among those interested in mental tests to break away from tests of the "all or none" type and to substitute for them a set of tests which permits of fractional grading. The "all or none" tests, it is argued, cannot be applied to a long series of subjects, whereas tests which may be rated for part-performance have a practically unlimited range of application. I suppose that both kinds of test will be retained, each in what turns out to be its proper sphere; and I am disposed to think that, for anthropological purposes, the "all or none" type should, at first and on the whole, be preferred. Everyone who has worked with Hering's instruments must have been struck by the fact that they serve admirably for their one predestined experiment but that they can with great difficulty, if at all, be adapted to other uses. The demands of undergraduate teaching have led most of us, perhaps, consciously or unconsciously to favor instruments of a more flexible, more variously usable sort. Yet it may be that, for the primitive subject, tests of Hering's kind are, at least in the beginning, the more desirable. I wonder if a large number of testlets, each one sharply cut to a particular purpose, might not be better than tests which require serial or repeated observation; and if the single-value result might not lend itself to mathematical treatment better than the somewhat arbitrarily chosen "representative" value of a test-series.

TWO NEW TERMS
CORMOPHYTASTER AND XENIOPHYTE
AXIOMATICALLY FUNDAMENTAL IN BOTANY

By WILLIAM TRELEASE.

(*Read April 14, 1916.*)

A generation ago botany possessed in the popular mind the unenviable reputation of being a dictionary study because of the rather large vocabulary necessitated by precise organography, though its terms were mostly self-evident to one possessing knowledge of the proper or current meaning of Latin roots. The specialization in biology that the last quarter-century has brought about has revealed so many new facts and ideas calling for equal precision that its burden of verbiage has grown inordinately, largely through the coining of Greek derivatives from roots not always used with apt differential meaning, *e. g.*, many words, of which I shall use several monotonously, in which the omnipresent "phyte" and "sperm" appear. This has grown, sometimes quite unnecessarily, to such a degree that a general biologist is likely to be puzzled by the language of a general treatise on either botany or zoology, while current publications on the newer branches of botany may be all but meaningless to a person familiar with the science at large,—sometimes, it must be confessed, when the essential ideas might have been conveyed in language intelligible to people of unspecialized training, and entirely free from technicalities.

Though I share the popular horror of pedantry or unnecessary technicality in expression, and would reduce rather than increase the vocabulary of specialization, it should not be understood that I fail to see that new knowledge and thought call for new expression, quite as much as new and varied tools became necessary as the rough construction of the stone age passed into the refined shaping of wood and metal that characterizes the age of steel; and the purpose

of the present communication is to propose the addition of two more to the words of precision of our day. Both of the new terms may be dispensed with, it is true, as they have been thus far, if one be disposed to paraphrase sufficiently, or to avoid reference to the well-known facts that they express; but these facts are so fundamental to a correct understanding of plant morphology that the latter course can scarcely be looked on as desirable, while the former—as every thinking teacher of the science has discovered—proves far from easy. One of them refers to the one-time division of the Vegetable Kingdom into Thallophytes and Cormophytes, now a question of morphology rather than of taxonomy; the other, also morphological, to the entities that compose the life cycle of one of the highest plants, whose alternating generations are usually spoken of as sporophyte and gametophyte (or the non-sexual and the sexual generation).

It is understood in a sense that the characters of genus, family and higher taxonomic groups are to be read into the characters of every species; but even novices know that this can be done only by reading into these group characters a number, sometimes large, of aberrations and exceptions; so that the popular idea of a thallophyte, with the body undifferentiated into stem and foliage, is not shaken by the occurrence of very stem-and-leaf-like algæ, any more than the popular idea of a cormophyte, with regularly disposed foliage on a supporting axis, is disturbed by seeing that a vegetating *Wolffia* possesses the simplest thallus configuration, though internally differentiated and in due season flowering like other cormophytes. The real difficulty lies in the fact that a more important difference exists between thallophytes and cormophytes, so that when properly defined these groups include respectively plants with the body undifferentiated morphologically; and plants with the body differentiated into root and shoot, the latter usually further differentiated into stem and leaf. These characters at once mark the mosses and liverworts as being neither thallophytes nor cormophytes, for although they possess what may be called stem and leaf they lack a morphological root. This is intensified by the universally understood circumstance that it is the sexual or gametophytic generation

in the mossworks that possesses stem and leaf, the non-sexual or sporophytic generation being undifferentiated, so that no real homologies are to be traced between the shoot of a mosswork and the shoot of a fernwork or seed plant. Hence it comes that careful botanists do not fall into the popular error of treating the mossworks as cormophytes because mosses and liverworks have what we usually speak of as stem and leaf, though the fact may be obscured, perhaps even when stated, that greater morphological reasons dictate the entire abandonment of the old and in a way convenient but now meaningless division of the Vegetable Kingdom into flowerless and flowering plants, in the former of which the heterogeneous assemblage called thallophytes and the well-defined taxonomic groups bryophytes and pteridophytes stand as coördinated. Even though we abandon thallophyte and cormophyte as of serious taxonomic use just as the subdivision of the former into fungi, algæ, and lichens is recognized as more suited to popular than to scientific diction, the essential fact remains that these two words, properly defined, stand for realities in morphology, which, supplemented by a comparable designation for the mossworks (which now bear only the group name bryophytes, comparable with pteridophytes and anthophytes or spermatophytes), divide the Vegetable Kingdom into three main divisions: THALLOPHYTES, with the body undifferentiated into morphological root, stem, and leaf; CORMOPHYTASTERS or pseudo-cormophytes, with differentiation of the sexual generation into cormoid and phylloid,—the so-called stem and leaf; and CORMOPHYTES, with differentiation of the non-sexual generation into root and shoot, and of the latter, usually, into true stem and leaf.

Recognition that with these gross characters are associated numerous structural details (*e. g.*, the absence of a specialized differentiation between sexual and non-sexual generation even in those thallophytes which by their nuclear behavior show an alternation of generations; the presence—as in many algæ—of pyrenoids and of large chromoplasts in the sexual generation of the liverwort *Anthoceros*, and of stomata—as in mosses and cormophytes—on its unusually evolved non-sexual generation; the appearance of a rudimentary conducting strand in the non-sexual generation of this liverwort and of mosses; the universal development of stomata and

of vascular tissue in the cormophytes) indicates the significance for phylogeny and morphology of the emphasis that is here laid on the coördination of thallophyte, cormophytaster and cormophyte in botanical terminology.

The second term proposed refers to what is commonly called the endosperm of angiospermous plants, sometimes spoken of as secondary endosperm. Very probably descriptive botanists will continue for a long time to speak of seeds as being albuminous or exalbuminous according as they possess or lack a food-reserve in the seed, which is used by the embryo in the early stages of germination. They have not been deterred greatly by the difficulty that sometimes exists in determining quickly whether or not this reserve tissue is really absent or merely reduced to so thin a layer as to be overlooked—though they try to indicate this difference; nor, for practical reasons, by the now very old knowledge that the ambiguity of the word albumen might make the employment of endosperm and perisperm in its place preferable in descriptive botany. Morphologists, however, have adopted the latter terminology of necessity, as indicating respectively food-reserve within or exterior to the embryo-sac or megaspore (as, of course, the name substituted for the inaccurate "macrospore" should have been coined),—"exalbuminous" seeds being those in which what would have remained as "albumen" has been used up during the maturing of the seed.

Quite as great mischief has been wrought here as with the terms thallophyte and cormophyte, by indiscriminate adoption of this betterment. Although the endosperm of a gymnosperm may be homologised with the endosperm of an angiosperm on the apparent but inapplicable ground that both are transient tissues formed within the embryo-sac, it is well known to every botanist that the gymnospermous endosperm—represented in angiosperms by antipodal cells and synergids—is really homologous with the sexual generation of bryophytes and pteridophytes; while the angiospermous endosperm, or secondary endosperm, originates from the "endosperm nucleus,"—after a process which can be called scarcely anything but fertilization except through an over refinement of definition.

If no other considerations were involved, the simplest way might be to speak of the gymnospermous endosperm and its homologue in

angiosperms as prothallus, at once indicating its equivalence with the structure known by this name in the higher cryptogams and facilitating remembrance of the close parallel between pteridophytes and spermatophytes in their alternation of generations; and to continue to speak of the angiospermous endosperm as "albumen." But quite apart from the undesirability of perpetuating the latter word except in the most general taxonomic usage, there is a deeplying morphological reason for giving a special designation to this "endosperm" of the highest plants.

From the point among thallophytes where an alternation of generations is first recognizable either in somatic or nuclear differentiation, that part of a life cycle which produces egg or sperm, or which has the haploid or as Lotsy has called it the x chromosome number, is spoken of as the gametophyte or sexual generation; and that part which produces neither egg nor sperm but begins with them, and which has the diploid or $2x$ chromosome number, is spoken of as the sporophyte or non-sexual generation. To be sure not all cells that are not haploid are diploid, for transient fusions of more than two nuclei are known, and the beginnings of the endosperm in a number of aberrant angiosperms start with a blended endosperm nucleus comprising several haploid nuclei; but it is characteristic of the reserve tissue in question that its origin is not in a reduction of chromosomes giving a haploid tissue (as in the gametophyte), or solely in a fusion of contiguous nuclei giving $2x$ (as usually in the sporophyte), or nx chromosomes (as in rare and exceptional tissues and in aberrant angiospermous endosperm), but that it is a structure distinctly not forming a part of either gametophyte or sporophyte. Its origin is found in a union involving the $2x$ or exceptionally nx "endosperm-nucleus" (itself derived from a union of the polar nuclei of a typical eight-nucleated embryo-sac, or from the fusion of several nuclei when this number has been increased), and a second nucleus of the pollen as yet indistinguishable from its sperm companion which unites with the egg to form the embryo or initial of the sporophyte; and this union differs from fertilization in the usual sense only in that one of the combining nuclei has already fused with one or more others so as to have more than haploid chromosomes.

This unit in angiosperms, neither sporophyte nor gametophyte, gives a first manifestation of crossing in cases where this can be recognized in the forming seed, *e. g.*, when sugary and starchy corn or kinds with colored and colorless endosperm are crossed, where the phenomenon has been called aptly *xenia*. The transient generation itself, but not necessarily accompanying hybridity, contrasted morphologically with sporophyte and gametophyte though neither, may be designated with convenience and propriety as the **XENIOPHYTE**.

The significance of this overlooked generation, confined to the most recent and highest of all plants, the angiosperms, not hinted at elsewhere in the Vegetable Kingdom, and originating from the gametophyte in as distinct specialization of gametoid initials as egg and sperm, is likely to claim serious attention as speculative reasons for evolutionary success and failure come more to the foreground, even though the *xeniophyte* appears to have reached its term with no more specialized development than the production of a sort of cambium zone and without having achieved the independence possessed by gametophyte and sporophyte—to the latter of which in its most evolved form the *xeniophyte* now serves as transient host.

THE UNIVERSITY OF ILLINOIS.

ON THE EFFECT OF CONTINUED ADMINISTRATION
OF CERTAIN POISONS TO THE DOMESTIC FOWL,
WITH SPECIAL REFERENCE TO THE
PROGENY.¹

By RAYMOND PEARL.

I. THE PROBLEM.

(Read April 15, 1916.)

One of the outstanding problems of genetics is that of the origin of new heritable variations. With the passage of time and the accumulation of exact experimental data it becomes increasingly clear that this factor is the basic one in all evolutionary change, whether progressive or retrogressive. Just now it is the fashion to speak of new heritable variations as mutations, but such designation does not appear either to make the facts concerned any different from what they were under an older terminology, nor does it essentially contribute to our knowledge about them. Indeed it is, so far as I can see, entirely fair to say that but little in the way of essential advance has been towards the solution of this problem since Darwin's examination and analysis of it. The two leading students of variation since Darwin, Bateson and De Vries, have to be sure, contributed greatly to our knowledge of certain aspects of the phenomena of variation; notably, on the one hand, in the direction of establishing a number of definite principles or laws of morphogenesis which control or determine in large degree the somatic expression of germinal differences, and, on the other hand, in very precisely and minutely analyzing the genetic behavior of various heritable variations, after they have appeared. But it is the problem of the origin, the determination, the causes of those *germinal* differences which lie behind somatic variations, and indeed *are* the

¹ Abstract of Paper No. 97 from the Biological Laboratory of the Maine Agricultural Experiment Station.

heritable variations, which appears to be the basic problem of genetics.

One may expose systematically the germ-cells of an animal to something unusual or abnormal in the surrounding conditions, and then analyze, so far as may be, not only the new heritable variations themselves (provided any such appear), but also the factors which underlie their causation. One is the more encouraged to undertake experimentation in this direction, because of the very interesting results of such studies which have been reported during the last few years, particularly those of Stockard² and Cole,³ with mammals and birds. In this connection mention should also be made of the work of Sumner with mice, Kammerer with lower vertebrates, Tower with insects, and MacDougal with plants.

The problems with which this investigation deals are specifically these:

1. Does the continued administration of ethyl alcohol (or similar narcotic poisons) to the domestic fowl induce precise and specific changes in the germinal material, such as to lead to new, heritable, somatic variations?
2. Failing a specific effect is there a general effect upon the germinal material leading to general degeneracy of the progeny?
3. What in general are the effects upon the soma of the treated individual of the continued administration of such poisons?
4. Are the somatic effects upon the treated individuals of a sort to give any clue as to the probable origin, or mechanism of the germinal changes?

The present paper reports, in brief abstract, the results obtained from the beginning of the experiment in September, 1914, to February 1, 1916. A complete report is now in process of publication in another place. In that report the data will be presented in detail, with probable errors, etc.

² Cf. for summary and bibliography of earlier papers Stockard, C. R., and Papanicolaou, G., "A Further Analysis of the Hereditary Transmission of Degeneracy and Deformities by the Descendants of Alcoholized Mammals," *Amer. Nat.*, Vol. L., pp. 65-88 and 144-177, 1916.

³ Cf. Cole, L. J., and Bachhuber, L. J., "The Effect of Lead on the Germ Cells of the Male Rabbit and Fowl as Indicated by their Progeny," *Proc. Soc. Exper. Biol. Med.*, Vol. XII., pp. 24-29, 1914.

II. MATERIAL AND METHODS.

General Plan.

The general plan of this investigation involves some features which have not been incorporated in earlier researches in this general field. In the first place, it was thought desirable to use *two* pure breeds of poultry for the foundation stock in the experiments rather than one, and in consequence of this make the offspring of the treated animals F_1 crossbreeds rather than pure-bred birds. The primary consideration in favor of this plan was that, by its adoption, a much more manifold opportunity seemed likely to be given to test any putative influence of the poisons on the germ plasm. It should be possible in an experiment of this sort to see whether in F_1 the usual conditions as to Mendelian dominance are in any manner or degree disturbed by the administration of the poisons to the parents. Further, when the F_1 individuals from treated parents are themselves bred there will be an opportunity to apply the most delicate of all genetic tests for the composition of the germ plasm, namely the test of segregation in F_2 and succeeding generations.

In the investigation here reported the foundation stock used came from pedigreed strains of two breeds, Black Hamburgs and Barred Plymouth Rocks. Both of the strains used have been so long pedigree bred by the writer, and used in such a variety of Mendelian experiments, that they may be regarded as "reagent strains," whose genetic behavior under ordinary circumstances may be predicted with a degree of probability amounting practically to complete certainty. Furthermore the results of crossing these two breeds reciprocally have been thoroughly studied by the writer.

Substances Used and Mode of Administration.

In the present investigation three different series of birds were started. To the birds in one series was administered 95 per cent. ethyl alcohol. To those in the second series was administered methyl alcohol, and to those in the third series, ether.

The method followed in these experiments for the administration of the poisons was essentially that which has been used by Stockard, namely the method of inhalation.

In the present experiments inhalation tanks of two different sizes have been used. They are essentially square boxes of galvanized iron, having at the top a round opening which serves as a means of entrance and exit for the bird. This opening is tightly closed by a cover during an experimental treatment. Below the bottom of the tank is a cylindrical reagent chamber closed by a tight fitting cover from below. In this projection below the floor of the tank proper is placed absorbent cotton saturated with the particular reagent used. Over the top of the reagent chamber is placed a piece of heavy galvanized wire gauze of about half-inch mesh which serves to complete the floor of the inhalation compartment proper, without obstructing the diffusion of the fumes from the reagent chamber.

Regarding the mode of administration of the poisons used it was found early in the work to be undesirable to depend entirely upon the evaporation of the reagent from cotton in the chamber at the bottom of the tank. This process took altogether too long a time to saturate the air of the tank with the vapor. Practically from the beginning we have used a combination of this method plus a preliminary saturating of the air with the vapor of the substance used by means of an atomizer. The routine procedure is this: there is placed in the reagent chamber at the bottom of the tank a piece of absorbent cotton soaked with the reagent to be used, ethyl or methyl alcohol or ether, as the case may be. Then the operator quickly but thoroughly fills the whole of the tank proper by means of an atomizer with a saturated vapor of the same substance. The birds to be treated are then introduced quickly, allowing as little as possible of the vapor to escape in the process. When the birds have been introduced the cover of the tank is tightly closed and left in that condition for one hour. It is to be understood throughout this paper that every bird designated as a "treated bird" has spent one hour every day in one of these tanks subjected to the fumes of the reagent specified in the particular case.

The number of treated birds used in the experiments to the date covered in this report is 19. The number of untreated control brothers and sisters is 58.

III. RESULTS.

A. In the Treated Individuals.

Before entering upon any discussion of the effect of the alcohol treatment on the progeny it seems desirable to examine with some care into the effects, both structural and physiological, upon the treated individuals themselves. In this examination attention will be confined to characters which are capable of quantitative definition and measurement. The main results are summarized in Table I.

TABLE I.

SHOWING IN SUMMARY FORM THE EFFECT OF CONTINUED ADMINISTRATION OF ALCOHOL (ETHYL AND METHYL) AND ETHER, BY THE INHALATION METHOD, UPON THE TREATED INDIVIDUALS THEMSELVES.

Character or Quality Studied.	Treated Individuals.	Untreated Controls.	Net Result on Alcoholists.
1. Mean number per bird of consecutive days of treatment	344.2	0	
2. Net percentage mortality (to Feb. 1, 1916) exclusive of birds accidentally killed	0	41.0	+
3. Mean body weight of females (in gms.)	3266	2953	-
4. Mean egg production per bird, 14 months	183.97	180.80	0
5. General activity	Reduced	Normal	-
6. Sexual activity	Reduced	Normal	-

The plan of this table is as follows: In the last column of the table a plus sign denotes that, with reference to the particular character discussed, the alcoholists have been favorably affected; a minus sign that they have been unfavorably affected as compared with untreated controls. A zero indicates that no effect of the treatment, one way or the other, has been detected.

From these summarized data it is possible to gain a tolerably clear comprehension of the objective happenings in these experiments so far. The treated animals themselves are not *conspicuously* worse or better than their untreated control sisters or brothers. The survivors, *i. e.*, those not killed by accident, are after roughly a year and a half of daily treatment, becoming a bit too fat for their best physiological economy, but except for that point, and the reduced activity which goes with it, they are very much like normal fowls.

Their apparently much better mortality record is indeed conspicuous, but in view of the small numbers involved, no great significance can be attached to it. It is probable that with larger numbers of birds as the experiments proceed this apparent superiority in relative mortality will disappear or be much reduced.

Regarding egg production the following details are of interest:

The egg production of the treated birds and the untreated controls was entirely normal in respect of its seasonal distribution, as well as in regard to its amount.

There has been no significant difference in the egg production of the treated birds and their untreated control sisters, either in the total average number of eggs produced per bird, or in the seasonal distribution of this production. Taking the whole untreated flock, the mean production per bird in the 15 months was 184.74 eggs, while the mean production for the treated birds was 183.97, making a difference of 0.77 egg in favor of the untreated. Taking the "special control" mean of 180.80 eggs there is a difference between this and the treated of 3.17 eggs in favor of the treated. Obviously the only conclusion which can be drawn from these insignificant differences is that the inhalation treatment has not affected the egg production of the birds, either favorably or adversely.

During the months of July, 1915, to October, 1915, inclusive the mean production of the treated birds fell below that of the control sisters. The difference between the two curves in this region, however, is no greater than may at any time occur between two similarly managed groups of sisters, according to the writer's experience with egg records. There appears to be no reason to attach any significance to this dip of the treated below the control curve. Taking the whole period covered by the report it is clear that the two curves wind about one another, now one, now the other being uppermost, just as curves for two random samples of the same material would be expected to do.

B. In the F_1 Progeny of Treated Individuals.

In this section of the paper it is proposed to discuss the effects, so far as any are observable, of the alcoholization of one or both of the parents upon the progeny in the first generation. Different

characters of the progeny will be considered, and as before primary attention will be given to such characters as admit of quantitative expression.

1. *Plan of Matings in 1915.*—The alcoholized birds and the untreated controls were mated early in February, 1915. Eggs were saved for incubation from these matings from about February 15.

The general plan of the matings in 1915 was to breed a treated male of each of the three classes, ethyl, methyl and ether, with (a) untreated control females, and (b) with treated females of his own class (*i. e.*, ethyl ♂ × ethyl ♀, methyl ♂ × methyl ♀, ether ♂ × ether ♀). In addition to these matings an untreated control male was mated with (a) untreated control females, (b) ethyl females, (c) methyl females, and (d) ether females.

All of the matings were of the type Black Hamburg ♂ × Barred Plymouth Rock ♀. There were produced 234 chicks from matings wherein one or both parents were treated.

2. *Germinal Dosage Index.*—In the present investigation the following reasoning has been used in devising a numerical expression of the dosage, so far as concerns the progeny. Two germ cells, a sperm and an ovum, unite to form the zygote of each progeny individual. It is proposed to designate as the "total germ dosage index" the total number of days during which the two gametes making the offspring zygote have been exposed to alcoholic influence while sojourning in the body of the treated individuals. Such a germ dosage index could, of course, be calculated for each individual progeny chick born. It seems, however, more desirable for present purposes to combine the figures for each mating, and take the sum of the number of days from the beginning of treatment of the male parent to the *average* date of hatching of the progeny, plus the number of days from the beginning of treatment of the female parent to the *average* date of hatching of the progeny as the germ dosage index for that mating. This can be expressed in a formula as follows:

Total germ dosage index in days = $(M_h - A_\sigma) + (M_h - A_\phi)$
where

M_h = Mean date of hatching of progeny.

A_σ = Date when treatment of ♂ parent began.

A_ϕ = Date when treatment of ♀ parent began.

The total germ dosage index for the F_1 progeny in these experiments ranges from 130 days to 354 days with the matings for the different substances used well scattered over the range.

3. *The Fertility and Hatching Quality of the Eggs from Alcoholized Parents.*—One of the surest and most delicate indicators of constitutional vigor and vitality in poultry which has yet been discovered is the hatching quality of the eggs. Anything which upsets the general metabolic balance or impairs the vitality of either partner in a mating will show its effect in a diminished hatching power of the eggs from that mating. In view of these facts an examination of the data relative to this character in these alcoholic matings becomes of especial interest. A summarized statement of the effects on the progeny is given in Table II.

TABLE II.

SHOWING IN SUMMARY FORM THE EFFECT OF CONTINUED ADMINISTRATION OF ALCOHOL (ETHYL AND METHYL) AND ETHER, BY THE INHALATION METHOD, UPON THE PROGENY.

Character Studied.	Offspring of				Net Result on Alcohol Offspring.
	Treated ♂♂ × Un- treated ♀♀.	Treated ♂♂ × Treated ♀♀.	All Treated Parents.	Untreated Controls	
1. Mean germ dosage index..	137.8	299.0	210.35	0	
2. Percentage of infertile eggs (i. e., eggs in which no zygote was formed).....	25.2	59.2	41.7	25.3	—
3a. Percentage of embryos dy- ing in shell.....	36.6	26.9	33.3	42.2	+
3b. Percentage of fertile eggs (i. e., zygotes) which hatched.....	63.0	72.3	66.7	57.8	+
4. Percentage of all eggs which hatched.....	47.1	29.4	38.6	44.4	—
5. Percentage mortality under 180 days of age.....	21.1	10.6	17.6	36.9	+
6. Percentage mortality over 180 days of age.....	5.9	13.6	10.3	15.3	+
7. Sex ratio: per cent. ♂♂..	48.9	45.5	47.7	50.0	0
8. Mean hatching weight per bird, males.....	34.91	36.97	—	34.24	+
9. Mean hatching weight per bird, females.....	35.04	37.17	—	34.73	+
10. Mean adult weight per bird, males.....	2,669	2,815	—	2,392	+
11. Mean adult weight per bird, females.....	2,020	2,063	—	1,928	+
12. Percentage of weak or de- formed chicks.....	0.7	0	0.4	1.0	+
13. Abnormalities of Mendelian inheritance.....	0	0	0	0	0

Summarizing the general features of the above results regarding production of offspring by alcoholized parents it may be said that the average percentage fertility of eggs is diminished and the average hatching power of the fertile eggs is increased after alcoholization of the parents. The reduction in average fertility of the eggs is due chiefly to the effect on the germ cells of the males and females, whose sexual activity is in general somewhat diminished by the treatment. Also alcoholized females are not as attractive to the males as untreated and hence are discriminated against in the matings, and furthermore probably the oviduct of the treated female does not furnish quite so favorable an environment for sperm as the oviduct of untreated females. The net result is that alcoholized parents produce on the average fewer offspring per mating unit than do normal, untreated parents under conditions otherwise similar.

4. *Mortality of F_1 Chicks.*—According to the results of earlier work in this general field it would be expected that there would be a decidedly higher rate of mortality among the offspring of the alcoholized parents than the normal.

Taking all the evidence of the present experiments into account, it admits of no doubt that the probability that a chick on the Maine Station's poultry range in 1915 would survive to maturity was not diminished, but, on the contrary, was in general substantially *increased*, if that chick's parents had both been subjected to a daily dosage of alcohol for from four to seven months before it was hatched. Since the chicks from treated parents were indiscriminately mixed with those from normal parents in housing, yarding, feeding, watering, etc., the fact that the former sort of chicks showed a lower mortality than the latter sort cannot be attributed to differential treatment after hatching.

5. *The Sex Ratio in the F_1 Progeny of Alcoholized Parents and Normal Parents of the Same Breeds.*—It has been claimed at various times and by various persons that the general metabolic condition of the parents at the time of conception is a factor in sex determination, or at least has an influence on the sex ratio.

The figures give no ground for asserting that the relative proportions of the sexes produced are significantly different in the alcoholic and normal control series. If the treatment has had an in-

fluence on this character it has been so slight as not to be statistically discernible in samples of the size here dealt with.

6. *Hatching Weight of F_1 Progeny.*—In the present series of experiments there is no significant difference in mean hatching weight between the offspring of treated males and the offspring of normal untreated control males when both are mated to normal untreated females. The slight differences which do appear are of the same order of magnitude as their probable errors.

Both the male and the female offspring of matings in which both parents were treated have a larger mean hatching weight (*i. e.*, are heavier when hatched) than the offspring of either completely normal control matings, or of matings in which the father only is treated. The differences here are relatively large and are statistically significant in comparison with their probable errors.

7. *Growth of the F_1 Progeny.*—Growth, as measured by increase in body weight, is universally recognized by physiologists and by practical animal husbandmen as one of the most valuable indices of innate constitutional vigor and vitality which it is possible to obtain. On this account it was thought to be of first-class importance to study the growth of the offspring from alcoholized as compared with untreated parents.

The offspring of alcoholized parents, whatever the nature of the mating, showed a higher mean adult body weight than offspring of untreated parents of the same breeds mated in the same way. This is true of both sexes.

In the case of the male chickens there was no substantial difference in the rate of growth in the three lots until after an age of about 100 days was passed. From that point on the male offspring of treated $\sigma\sigma \times$ untreated and treated $\sigma\sigma \times$ treated $\sigma\sigma$ grew at a more rapid rate than the controls. The differences in mean body weight for a given age became increasingly large as the age advanced. At 200 days of age we have by interpolation on the curves the following set of comparative mean body weights.

COMPARATIVE MEAN BODY WEIGHTS AT 200 DAYS OF AGE.

	Absolute Weight.	Relative Weight.
Males <i>ex</i> untreated $\sigma\sigma \times$ untreated $\sigma\sigma$	2,392.32 gm.	100
Males <i>ex</i> treated $\sigma\sigma \times$ untreated $\sigma\sigma$	2,668.97 gm.	112
Males <i>ex</i> treated $\sigma\sigma \times$ treated $\sigma\sigma$	2,815.25 gm.	118

In the case of the female chickens there was no substantial difference in the rate of growth in the three lots until after an age of about 150 days was passed. During the next 25 days the controls grew faster than the chicks from treated parents. At and after 200 days of age, however, the offspring of treated parents (one and both) showed a higher mean body weight than the controls. We have the following set of comparative mean body weights at 250 days of age, obtained by interpolation on the curves.

COMPARATIVE MEAN BODY WEIGHTS AT 250 DAYS OF AGE.

	Absolute Weight.	Relative Weight.
Females <i>ex</i> untreated ♂♂ × untreated ♀♀	1,927.72 gm.	100
Females <i>ex</i> treated ♂♂ × untreated ♀♀	2,020.38 gm.	105
Females <i>ex</i> treated ♂♂ × treated ♀♀	2,062.98 gm.	107

At all ages in the case of the male chicks, and in all ages but two (12.5 and 19.5 days) in the case of the female chicks, the mean body weight of the offspring having both parents alcoholic was higher than that of the offspring having one parent only, the father, alcoholic. The differences are, for the most part, insignificant in comparison with their probable errors, but the uniformity with which the "both parents treated" curves maintain their superiority over the "father only treated" curves is noteworthy, and significant.

There are no distinctive differences in relative variability between the three different lots of chicks. In general the relative variability tends to diminish after an age of about 30 days is past.

The evidence derived from a study of the growth of the chickens in this experiment lends no support to the view that parental alcoholism necessarily reduces the vitality of the offspring or induces degeneracy. On the contrary the data plainly indicate that the offspring of alcoholized parents are in some degree superior in vigor and vitality to those from untreated parents.

8. *Deformities in the F₁ Progeny.*—One of the most striking features of Stockard's results on the alcoholization of guinea pigs is that a considerable percentage of the progeny of treated parents exhibit gross malformations of various organs, particularly the eyes. In the present experiments with poultry, nothing of this sort has made its appearance. The proportion of such abnormal chicks

produced in the breeding season of 1915 from alcoholized parents was no greater than the number produced from untreated parents. In actual fact there was exactly *one* chicken out of 234 hatched from alcoholized parents in 1915 that was too weak to band, and was in consequence killed at the time of hatching. None was deformed. Out of 1,527 chicks from untreated parents, 16, or 1.0 per cent., were weak or deformed or both.

DISCUSSION OF RESULTS.

We have seen that *out of 12 different characters for which we have exact quantitative data, the offspring of treated parents taken as a group are superior to the offspring of untreated parents in 8 characters.* The offspring of untreated parents are superior to those of the alcoholists in respect of but two characters, and these are characters which are quite highly correlated with each other and really should be counted as but a single character. Finally with respect to two character groups there is no difference between the alcoholists and the non-alcoholists. The character groups which have been dealt with in this study, and for which definite *quantitative* data are herein presented, seem to cover a much wider range of physiological and genetic factors and phenomena than has ever been included or even approached in any previous study regarding the effects of parental alcoholism upon the progeny. They have the further advantage of being characters which are measurable (either statistically or otherwise) and on that account greatly reduce, if they do not entirely eliminate, the possibility of personal bias or prejudice influencing the results.

The mutual accord of the results from characters involving such a manifold range of physiological factors is striking. This fact in considerable degree offsets the fact that as yet our series of experimental animals is statistically small, leading to such large probable errors that the individual differences are not in every case significant in comparison with their probable errors. The experiments are of course being continued and expanded, and concurrently the probable errors of differences are being reduced. If results in the same sense as the present ones continue to appear (as seems to

be the case) they are bound presently to become very convincing to such persons as are not prevented by prejudice from accepting or appreciating scientific evidence on the problem of the effect of parental alcoholism upon the progeny.

We may evaluate our results in general terms as follows:

1. There is no evidence that *specific* germinal changes have been induced by the alcoholic treatment, at least in those germ cells which produced zygotes.

2. There is no evidence that the germ cells *which produced zygotes* have in any respect been injured or deleteriously affected.

3. The results with poultry are in *apparent* contradiction to the results of Stockard, Cole and others with mammals. I believe, for reasons which will presently appear, that this contradiction is only apparent and not real, paradoxical as such a statement may appear.

4. The results with poultry are in a number of important respects in essentially complete agreement with those of Elderton and Pearson⁴ on parental alcoholism in man, and of Nice⁵ in mice.

The interpretation of these results which seems to account best for all the facts is that the apparent discrepancy between the avian and mammalian results is fundamentally due to a difference in degree of resistance of the germ cells to alcohol. On this basis it is possible, I believe, to frame an hypothesis which will bring together in a satisfactory manner under one point of view the apparently discrepant results of Stockard, Pearson, Nice and the writer.

At the outstart let us remind ourselves of a point which one is apt to overlook in considering results of this sort, namely that the germ cells which produce the zygotes, which are the progeny of our experiments, are only a very minute fraction of all the germ cells which the parents produce. Let X be the total number of germ cells (ova or spermatozoa) which the individual produces, and let a be the number which succeed in taking part in the formation of

⁴ Elderton, E. M., and Pearson, K., "A First Study of the Influence of Parental Alcoholism on the Physique and Ability of the Offspring," *Eugenics Lab. Mem.*, X., pp. 1-46, 1910. (Second edition.)

⁵ Nice, L. B., "Comparative Studies on the Effects of Alcohol, Nicotine, Tobacco Smoke, and Caffeine on White Mice. I. Effects on Reproduction and Growth," *Jour. Exper. Zool.*, Vol. 12, pp. 133-152, 1912.

a zygote, and let A be the number which do not so succeed. Then, of course, $A = X - a$, or put the other way about,

$$X = A + a.$$

This is the fundamental gametic equation. We know that A is enormously greater than a . There is furthermore a great deal of evidence that a is not a random sample of X , but on the contrary is a highly selected sample. To Roux in his "*Kampf der Theile*" is to be given the credit for first pointing out what now seems axiomatic, that there is constantly going on a struggle for survival among the cells of the organism, the physiologically "best" being the survivors. To the philosophical breeder of animals nothing seems more certainly established than that this process of selection is constantly going on and is of very special importance among the germ cells. Direct and convincing observational and experimental proof of it has been given by the double mating experiments which Cole and Davis and Cole and Bachhuber have carried out.

Granting the existence of variation in the vigor or resisting power of germ cells we have the necessary basis for the action of a selective agent. The hypothesis which we wish to suggest is that alcohol acts as such a selective agent upon the germ cells of alcoholized animals. The essential points in such an hypothesis may be put in the following way.

1. Assume the *relative* vigor, or resisting power of germ cells varies or grades continuously from a low degree, say 1, to a high degree, say 10, and further assume that the *absolute* vigor of the whole population of germ cells, measured by the mean let us say, is different for different species.

2. In the intensity of dosage employed in inhalation experiments alcohol does not destroy or functionally inactivate *all* germ cells. The proportionate number of the whole population of germ cells which will be inactivated by such dosage may fairly be supposed to depend upon the mean *absolute* vigor or resisting power characteristic of the particular species or strain used. In a species with germ cells of absolutely low mean vigor proportionately more will be functionally inactivated than in a species of high absolute mean vigor of germ cells.

3. Besides the germ cells which are wholly inactivated by the

deleterious agent, and which we may designate as class (*a*), we may fairly assume that there is a possibility of two other classes existing, viz., (*b*) germ cells which, while not completely inactivated, are so injured by the agent as to produce zygotes which are measurably defective in some degree, and (*c*) germ cells which are not measurably affected by the agent at all in the dosage employed, and produce zygotes which are not discernibly otherwise than perfectly normal.

4. It appears entirely fair to assume that germ cells of the (*a*) class are of relatively the lowest mean vigor or resisting power, class (*b*) next, and class (*c*) the highest. The proportionate number of the two sorts of zygotes corresponding to classes (*b*) and (*c*) of germ cells which would be expected to appear in any experiments made to test the point would clearly be a function of the mutual relationship or proportionality between two variables, the dosage of the deleterious agent on the one hand, and the mean absolute resisting power of the germ cells characteristic of the strain or species of animal used in the experiments on the other hand.

5. If the dosage of the agent be relatively *high* in proportion to the mean absolute resisting power it would be expected that all the germ cells would fall into classes (*a*) and (*b*), producing no zygotes at all or zygotes in *some degree* defective. This about represents the condition, so far as can be judged from the data given, with Stockard's alcoholized guinea pigs and Weller's⁶ lead-poisoned guinea pigs. The dosage is sufficiently high in proportion to the absolute germinal resisting power that all or practically all of the offspring are defective in greater or less degree and in reference to some one or more characters. Stockard's F_2 and F_3 results indicate that though the untreated F_1 animals from alcoholists may appear normal, they really are somewhat defective.

6. If, on the other hand, the dosage, though *absolutely* the same, be relatively *lower* in proportion to the mean absolute resisting power of the germ cells it would be expected that all three germ cell classes (*a*), (*b*) and (*c*) would be represented. The zygotes actually formed would be chiefly produced by (*c*) germ cells, and to a much smaller extent by (*b*) cells. Under these circumstances it would necessarily follow that a random sample of the zygotes

⁶ Weller, C. V., "The Blastophthoric Effect of Chronic Lead Poisoning," *Jour. Med. Research*, N. S., Vol. XXVIII., pp. 271-293, 1915.

produced *after* the action of the deleterious agent would, on the average, be superior in respect to such qualities as growth, etc., which may be supposed to depend in part at least upon germinal vigor, to a random sample of zygotes formed *before* the action of the agent, because the germ cells of class (*c*) are a selected superior portion of the total gametic population.

7. Essentially that proportionality between effective dosage of the deleterious agent and absolute resisting power of the germ cells outlined in the preceding paragraph (6) is believed to have obtained in the present experiments with fowls, Nice's experiments with mice, and nature's experiments with the workmen's populations studied statistically by Elderton and Pearson.

There is much detailed evidence which can be adduced from my own experiments and from the literature in support of the above hypothesis. This evidence will be discussed in the complete paper.

Finally, I wish again to emphasize that, in my opinion, the results here set forth are not contradictory to those of Stockard. Anyone who bases a criticism of his results on the present experiments will go beyond the facts. Our results seem to me to be supplementary to those of Stockard, and to throw an interesting light on the need for caution in reaching a correct interpretation of all experiments in which a mildly deleterious agent acts upon the organism. It would seem clear that there is need for caution in this difficult field. If the conclusions as to the utterly dreadful and relentlessly certain effects of parental alcoholism on the progeny which have been transported, as it seems to me somewhat recklessly, from Stockard's guinea pigs to human beings, were really true for the latter, then I can see no escape from the further conclusion that a great majority of the individuals belonging to the higher intellectual and social classes in the countries of Western Europe today ought to be blind, dwarfed, and degenerate wretches, because social history gives definite and uncontrovertible evidence that their parents and their grandparents on the average consumed proportionately as much and probably more alcohol than the corresponding generations of Stockard's guinea pigs. The absence of general degeneracy in these social classes could not be more completely and scientifically demonstrated than it has been by the events of the past two years.

The experiments here reported are being continued.

AMERICA AS THE DEFENDER OF NEUTRAL RIGHTS.

BY L. S. ROWE, PH.D., LL.D.

(Read April 13, 1916.)

To the historian of international law, the year 1915 will stand forth as marking a crisis in the development of the spirit of legality, similar in many respects to the crisis of the early years of the nineteenth century. It is too early to predict the condition in which our system of international law will emerge from the present conflict, but it is evident that this condition will depend in large part on the attitude and policy of America. It is no less clear that at the close of the present struggle the system of international law must be subjected to revision of a far-reaching character. The lack of harmony between the rules of international law and the conditions of modern warfare has been a source of constant irritation, and it is of great importance to the world's peace that these causes of irritation be removed.

Whatever may be the nature of these changes, it is evident that the pressing, immediate problem is to preserve the existing fabric of international law, and to await the termination of the war before any radical changes are undertaken. The civilized world, and particularly the neutral nations, look to America to assume the leadership in the performance of this world service. That the United States is called upon to play an important part in the performance of this service is attested by the contributions of this country to the development of international law during the nineteenth century. These contributions point the way to the larger rôle which we are now called upon to play.

We sometimes take for granted that there is an inherent and inevitable tendency of international law constantly to develop toward a higher and higher plane, and forget that there have been several periods in history during which the achievements of one epoch have been sacrificed by its successor. The shifting of the equilibrium of

power from the basin of the Mediterranean to northern Europe is probably the most striking illustration of the loss involved when belligerent interests find no countervailing force.

The situation which confronts us today marks another epoch in the development of international law. The issue is clearly and definitely formulated: shall the interests of belligerents reshape and determine the fabric of international law, or shall neutral interests become an increasingly dominant influence in establishing the rules that shall govern the relations between states?

Recent events in Europe have placed a new aspect on the part which America is called upon to play in the development of international law. The appeals of all the contending parties to accepted legal principles, as justification for their respective policies, is sufficient indication of a deeply-rooted respect for the "*opinion of mankind*," which is, in the last analysis, the basis of the spirit of legality; both in municipal and in international law.

In spite of the constant appeals to established legal principles by all parties, there is noticeable a disquieting and dangerous tendency to encroach upon those neutral rights, the observance of which represents the results of a long and bitter struggle, marking one of the great achievements, if not the greatest achievement, of the nineteenth century. The broadening of the rights of neutrals has been accompanied by a corresponding development of neutral obligations. Viewed from the broadest possible standpoint, the development of neutral rights and obligations represents the most important step, first, in narrowing the area of conflict, and, secondly, in developing that world spirit of legality and settled rule which is the fundamental as well as the ultimate purpose of international law.

Under the guise of adapting the principles of international law to the new conditions of warfare, the policy pursued by the parties to the present conflict has not only undermined the basis of neutral rights, but threatens to destroy the hard-earned gains of the nineteenth century. We are apt to forget at times that the recognition of neutral rights is a matter of so recent development that it represents the least stable division of international law. It is becoming increasingly evident, furthermore, that the interests of advancing

civilization are so closely bound up with a broadening recognition of the rights of neutrals that the defense of the ground gained during the nineteenth century acquires a new significance and a new dignity.

It is this situation that places upon the republics of the American Continent a new and far-reaching obligation. Their defense of the rights of neutrals will be all the more effective if they are conscious of the fact that in making such defense they are at the same time furthering the higher interests of humanity. There is a noticeable tendency in the state documents issued by the parties to the present struggle, to take the view that while neutral rights are all very well in their way,* they can only be recognized in so far as they do not interfere with the effective waging of war. It is this spirit which dominates the British proclamation of November 2, 1914, the German declaration of February 4, 1915, and the British Order in Council of March 15, 1915. In reading these documents one has the impression of being thrown back into an earlier and more primitive period. Even in language there is a striking similarity with some of the documents issued during the Napoleonic struggle. It requires little or no effort to understand the point of view which has dictated these documents, and one can not even repress a certain sympathetic understanding of measures which are undoubtedly intended either to safeguard fundamental national interests, or dictated by considerations which are believed to be necessary to national self-preservation. But it is also well to remember that Napoleon as well as the Allies were quite as sincere in 1807 as are the belligerents of 1916, and that had it not been for the "Armed Neutrality," on the one hand, and the influence of the United States, on the other, the last vestige of neutral rights would have disappeared, and with such disappearance civilization would have descended to a distinctly lower plane.

International as well as municipal law develops as a result of a compromise between conflicting interests, real or imaginary, and to allow any state or group of states in the society of nations to pursue a policy in flagrant disregard of the rights of third parties, is to destroy the basis of order, law and settled rule. It is this situation which places so heavy a responsibility on the republics of

the American Continent. By the inevitable logic of events they have become the only effective defenders of neutral rights, and unless they unitedly respond to the call they will become accomplices in the destruction of that delicate fabric of international law which represents the triumph of world interest over selfish national design, and which is the expression of the spirit of social order in international affairs.

The obligation assumes the character and dignity of a world duty, and can only be effectively performed through the united action of the American republics. It is true that the interests of the neutral nations of Europe are in many respects similar to our own, and there is every reason to hope and expect that they will support the united policy of the nations of the American continent. There is, however, much to be gained in giving to the principles which we are prepared to support a distinctive American background, and in emphasizing the fact that in the present crisis of the world's affairs the republics of America have not only become the special guardians and custodians of neutral rights, but are also prepared to fulfil with no less zeal, every neutral obligation. The world service which the republics of America are called upon to perform, through their united action, is of a two-fold character:

First. They must firmly and unitedly maintain those neutral rights which have received the sanction of long continued practice and observance, and

Second. They must be prepared to carry one step further the law relating to neutral rights and obligations.

As regards the first point, we cannot hope to make much progress unless it is possible firmly to establish the principle that belligerent convenience is no adequate basis for a system of international law and that, in fact, such a principle is destructive of all law.

The most notable advances in international law have been made because of the increasing importance of neutral interests and the compromises which belligerents have been compelled to make because of this fact. With each conflict there is evident a tendency on the part of belligerents to undermine, usually through forced and unnatural interpretation, the accepted principles of international

law, and it is only when this tendency is opposed by the definite and concerted assertion of neutral rights that the international legal structure is maintained. This situation makes the concerted assertion of neutral rights in the present crisis a matter of vital importance, in view of the manifest and natural tendency on the part of all belligerents to make belligerent convenience the sole and final test of legality.

At no time since the Napoleonic struggle has such an opportunity offered itself to the neutral countries of the civilized world. The republics of the American continent should lose no time in reaching a clear and definite agreement as to the rights which they are prepared to maintain. So strong has become the influence of world opinion on the action of individual states that such a concerted and united action would have a far-reaching effect in preserving the rights sanctioned by law and usage and, after the close of this conflict, in securing the recognition of new principles which, by reason of their influence in narrowing the area of conflict, are calculated to promote the broader interests of civilization. It would have been a splendid example of continental solidarity, if at the outbreak of the European war, the delegates of the republics of America had assembled and remained in permanent session for the maintenance of neutral rights, as well as to consider the scope and limits of their neutral obligations.

"What," it will be asked, "are the specific things for which such a league of neutrals should strive?"

It would involve too great an encroachment upon your time to take up, with any degree of detail, the specific rights which should be made the subject of concerted action. Such a discussion would, in reality, involve a commentary on the entire law of neutrality. The real point that I wish to make is that we should learn to think and act "continentally" on these great basic questions which affect so intimately the spirit of order and legality in international affairs. It is undoubtedly true that the modern conditions of maritime warfare call for a modification of certain of the accepted principles of international law, but if the extent and character of such modifications are to be determined exclusively by belligerent convenience,

we are certain to descend to a lower plane in the adjustment of international relations. It may well be that the Declaration of Paris requires revision, and that the Declaration of London no longer meets present needs, but in such revision the voice and influence of non-belligerents should be heard and given due weight. Probably the most pressing questions upon which neutral action is necessary are:

First. Shall we admit the right of belligerents indefinitely to extend the list of contraband articles, so that the distinction between absolute and conditional contraband practically disappears?

Second. Shall we accede to the rule that the doctrine of continuous voyage can under any circumstances be applied to conditional contraband?

Third. Shall we admit of the refining away of the distinction between a "naval or military base," and all the other ports of a country, so as practically to destroy the distinction?

Fourth. Shall we agree to a reestablishment of the old rule of the Consulate del Mare, that enemy goods on board neutral vessels are liable to capture, even if such goods are not contraband of war?

Fifth. Shall we accede to the new definition of blockade, and to the penalties attached to the violation thereof?

Sixth. Shall we agree to the new interpretation placed on the "right of search"?

Seventh. Shall we tolerate the hovering of belligerent cruisers along the coast line of the republics of America.

Eighth. Serious consideration should also be given to the plan proposed by the Museo Social Argentine, which has aroused much discussion in the countries of South America. This important organization proposed, soon after the outbreak of the war, that steps should be taken by the republics of America to eliminate belligerent operations from American waters, and also to secure the freedom of all purely inter-American commerce, irrespective of the question whether such commerce was carried in neutral or belligerent bottoms. While this represents a most important extension of neutral rights, the recognition of such a principle would have avoided much unnecessary suffering inflicted on the American republics by reason of the European conflict.

These are all questions the mere formulation of which indicates how deeply they affect the structure of international law. In a period characterized by extreme retaliatory measures by all parties to the conflict, it is not likely that any real and permanent results can be secured in preserving the structure of international law unless the efforts receive united support.

It is also incumbent upon the republics of America to give due consideration to the question of neutral obligations. The unsatisfactory condition of the law in this respect has been illustrated time and again during the course of this war in the abuse of the hospitality of neutral ports to secure coal, supplies and provisions for belligerent squadrons. While the letter of the law has been complied with, its spirit has been constantly violated, and the question now presents itself with renewed insistence whether important modifications should not be introduced into the law regulating the obligations of neutrals in order effectively to guard against such abuses.

The outbreak of the European war came so unexpectedly, dealing such a severe blow to the economic and financial interests of all the republics of America, that the first period of bewilderment was followed by a period of anxious questioning with reference to their position as neutrals. The uncertainties and anxieties of the situation were increased by the presence of belligerent squadrons in the south Atlantic and south Pacific. The question of the interpretation of the rules relating to the shipment of supplies ostensibly shipped in pursuance of legitimate commercial transactions, but in reality intended for belligerent cruisers on the high seas, presented a problem so difficult and delicate that no one country could hope alone to grapple with the problem in a satisfactory way. Similarly the question of preventing the ports of America from becoming bases of operation was an exceedingly difficult one owing in part to the extended coast line, and partly to the inadequate facilities for patrolling the same. It was here that the opportunity presented itself to the republics of America to assume a real position of leadership in the preservation of international law.

When the war broke out all arrangements had been completed for the assembling of a Pan-American Conference in Santiago,

Chile, in October, 1914. The machinery was, therefore, ready for the holding of a Congress of neutrals which might have performed a great service in the more definite formulation of neutral rights and neutral obligations. The healthful restraint imposed on belligerents by reason of the presence of vigorous and united neutral interests has been lacking, and the result has been a marked and disquieting decline in the standards of international dealings.

Although the most effective moment for an united stand of the neutral nations of America would have been immediately after the outbreak of the European war, it is not too late to repair at least some of the damage that has been done. The machinery for such a conference is at hand in the International Commission of Jurists provided for by the Pan-American Conference of 1910. This body should be called immediately and remain in permanent session as a Congress of neutrals until the close of the war. Its deliberations and conclusions should have to do with the rights which the neutral nations of America are prepared to maintain, and the obligations which they are prepared to fulfill. The mere fact that such a Congress is in permanent session cannot help but impress itself upon the imagination of the entire civilized world, and have a far-reaching effect on the policy of the belligerent nations. Not only would such a Congress serve to preserve the spirit of legality, but it would give to the world an example of international solidarity which would mark an epoch in the history of international relations. To allow such an opportunity to slip by is to prove ourselves unworthy of the great mission entrusted to the free nations of America and to proclaim ourselves unable to defend the highest interests of civilization.

LEGAL AND POLITICAL INTERNATIONAL QUESTIONS AND THE RECURRENCE OF WAR.

By THOMAS WILLING BALCH.

(Read April 15, 1916.)

A recourse to war in our day is such a terrible visitation not only for the belligerent nations but also in the long run through its indirect effects for all neutral powers as well, that humanity of late years has cried aloud more insistently perhaps than at any other period of history for some way of avoiding the scourge of war. Unfortunately as yet it is not generally appreciated that the real causes which produce war are deep-seated and not generally apparent on the surface, while the events which as a rule actually precipitate war are in themselves more or less of trifling importance.

Though we cannot see the elimination from the world of all war any more clearly than we can look for the complete eradication of consumption or cancer, nevertheless, international publicists are working to find a way to save the world from the woes inflicted by war with as stout hearts and as much hope of success as the surgeons, physicians, chemists and others who are working to guard humanity from bodily disease and ailment. And how international justice shall in all cases be substituted for war as arbiter between nations, is as difficult a problem calling for solution as any known to the human intelligence.

To-day I shall present for your consideration especially one point of this problem, to wit, that the causes of disagreement arising between the members of the family of nations seem to divide naturally into two great groups. Into one of these groups fall the cases which can be settled by invoking jural rules, while to the other group belong those problems which usually call for an appeal sooner or later to war. To the former of those two groups of cases belong all the cases of difference which, however they may be decided in favor of one contestant or the other do not really affect

the future political development and power in the world of either party to the cause of difference. To the latter group belong all the cases of difference upon whose solution depends the future political power and prestige in the world of one or more of the contesting nations.

As far back at least as the first suggestion of the Geneva Tribunal, discerning jurists and publicists had appreciated that the cases of disagreement which arose between nations naturally separated into these two groups of cases, the first of which is more strictly legal, and the second of which is more strictly political. And as more and more of the former class of cases, that is legal cases, were successfully referred for settlement to international tribunals named *ad hoc*, while at the same time cases of the second group, that is political cases, were referred to the arbitrament of war, the vital difference between these two classes of international cases became apparent to an ever-growing number of jurists. And the present war should make it clear to every one possessed of ordinary common sense, that as the social organism of the world is now constituted, there can be no hope of eliminating all wars. For where it becomes not a question of which of two nations or groups of nations is right, according to the rules and usages of the law between nations, but which of such contestants shall have the power to map out the political policy of a larger or smaller portion of the world in its own interest, a judicial court, even were a supreme court of the world in existence, could not decide which side was the stronger. All that a court of law can do is to decide which contestant is right according to the law. And between municipal and international tribunals there is this radical difference at present; that back of the former there is the whole police and military force of the state of which any given court is an organ to enforce the judgment of that court. While back of an international tribunal to-day there is only the public opinion of the world, and the military power of one of the contestants, or one group of contestants to any case to insure the acceptance of the decision. And if the last sanction is invoked it means a return to the original arbitrament of war.

To designate these two great classes of cases into which the questions of difference arising between nations naturally seem to

divide, the French publicists have used the terms *cas juridiques* and *cas politiques* to describe respectively the cases that are susceptible of a judicial solution and those which are not. In England, Westlake¹ and Oppenheim² have used the terms *legal* and *political* cases to designate respectively the cases which may be solved by an appeal to judicial procedure, and the cases which seem to lead sooner or later to war. Among American publicists Hershey³ also has used the terms *legal* and *political*. Likewise in the proceedings of the two Hague Peace Conferences, the terms *juridique* and *legal* were used respectively in French and English.⁴ Of late years pacifists in this country have applied to those two great divisions of international questions the terms *justiciable* and *non-justiciable*. These latter terms, however, are not so good as the terms *legal* and *political* used by the great British international publicists and commentators. For the word *justiciable* is distinguished from the word *justifiable* by a difference of only one letter, and as a consequence a confusion of the words is liable to arise in the popular prints. Also the expression *non-justiciable* is a negative term and consequently inferior for that reason to the expression *political* which is a positive term.

Following the nomenclature devised for the purpose by the great French and British international jurisconsults and commentators, I have applied to these two great categories of international questions, the terms *legal* and *political* cases respectively. And in an effort to differentiate between the cases which so far nations have been willing to refer to judicial settlement, that is *legal* cases, and those which nations have preferred to submit to the decision of war, that is *political* cases, the present writer ventured to advance at the close of 1913 the following definitions of *legal* and *political* cases in the affairs of nations.⁵

¹ Thomas Balch, "International Courts of Arbitration," 1874, 6th edition, Philadelphia, 1915, page 63.

² Lassa Oppenheim, "International Law," 2d edition, London, 1912, Volume II., page 1.

³ Amos S. Hershey, "Essentials of International Public Law," New York, 1912, pages 323, 338.

⁴ A. Pearce Higgins, "The Hague Peace Conferences," Cambridge at the University Press, 1909, pages 122-123.

⁵ Thomas Willing Balch, "Différends juridiques et politiques dans les rapports des Nations: Revue Générale de Droit International Public," Paris, 1914, page 181.

In any investigation of how far judicial settlements have and can be successfully substituted for war in deciding the differences arising between nations, it is necessary to look far back in the history of our own period of civilization to examine the political changes which gradually led to the formation of what we now call nations, and also to scan carefully the attempts which have been made in the past to mitigate the severity and curtail the area of war.

When feudalism had developed and extended throughout Europe, the relations of man to man upon which feudalism was based resulted in a constant clashing of individuals over matters of more or less moment without, however, the existence of any restraining force to compel individuals to keep their quarrels within bounds so as not to cause detriment to the political life and well-being of other individuals who were not interested in the cause of discord. As a consequence, it was perfectly proper for one feudal lord who was at war with another feudal ruler but whose lands did not touch, indeed might even be far apart, according to the means of communication of the times, to march his retainers and men-at-arms across the lands of the intervening neighbors who had no cause of quarrel with either of the belligerent lords. The warring lords in so doing were merely making use of the public highways. Gradually there began to form, first in the west of Europe, by the grouping

"The expression, *legal cases*, should be recognized to mean questions arising between nations which, while a cause of dispute between two or more sovereign states, *do not* threaten by their solution in favor of one side or the other, the independence or any vital interest of either party. The expression, *legal cases*, furthermore, should be recognized to apply to all those cases which do not affect the vital interests of the contesting nations, whether there are or are not rules of the law of nations upon which the majority of the great powers of the world are agreed, ready at hand to apply to such cases in arriving at a judicial decision for their solution.

"The expression, *political cases*, should be recognized to mean questions arising between states which, owing to the facts and interests involved in those cases, *do* threaten, in any attempt to solve those questions by a judicial decision, in the future to affect and alter either favorably or unfavorably the political power and influence of one or more of the nations parties to the controversy. The expression, *political cases*, furthermore, should be recognized to apply to all those cases which do affect the vital interests of the contending nations; even though there may be rules of international law generally recognized by the nations the application of which to those cases would decide them strictly on legal grounds in favor of one side or the other."

of many fiefs, both small and large but speaking similar dialects or patois, round one overlord, generally called a king, a new kind of political organism. Based roughly upon a similarity of language there began to grow up slowly at the expense of feudalism the kingdoms of France, England, Spain, Sweden, Saxony, Brandenburg, and various other political bodies which were the ancestors of the modern European nations. In these newly forming political organisms, the relation of the overlord to his vassals and their subjects was not one that permitted an indirect allegiance of the subjects of his vassals to the overlord as was the case in purely feudal times. The Kings of France, of England,⁶ of Scotland, of Sweden, of Denmark, the Electors of Saxony, of Bavaria, of Brandenburg, the Grand Dukes of Nassau, of Baden, demanded and obtained more and more a direct allegiance from all their subjects regardless of the claims of the feudal nobility as middle men to interpose their claims of sovereignty between their sovereign liege, the king, or elector, or grand duke or as the case might be, and their own immediate tenantry and personal men-at-arms. By degrees the political relations between all of the latter, whether men-at-arms or peasants, and the king became as direct a personal relation as that between the king and his immediate feudal vassals. Gradually the sovereign entity of the feudal nobles disappeared and became merged in the ever growing power of the king or overlord. In that way the modern nations of Europe were slowly formed.

⁶ The feudal relation introduced in England by Duke William of Normandy marked an important step forward towards the development of the nations as they exist to-day. For William the Conqueror required from all feudal vassals of every degree in England an allegiance to himself as king. The difference in feudalism as thus established in England from the feudalism developed in France and elsewhere on the continent may best be shown by the difference in the French and the English feudal oaths which in substance were as follows:

THE FRENCH FEUDAL OATH.

On bended knee and with uncovered head I make myself thy man of life and limb and earthly honour.

THE ENGLISH FEUDAL OATH.

On bended knee and with uncovered head I make myself thy man of life and limb and earthly honour, saving my allegiance to my lord the King.

Thus on some islands in the river Seine in the northern part of modern France a settlement started which in time developed into the city of Paris. The islands were chosen as a place of settlement in the beginning because the water about them formed a natural boulevard against attack. A line of fighting men gained the local feudal lordship there; and in the course of time they extended their landed possessions to both banks of the river and then bit by bit in all directions. From one of their number, Hugh Capet, though he was not the first of his line to rule there, the family came to be known as the Capetians. Then, as time passed, the territorial domains of the Capetians and their Valois successors was extended still farther, sometimes by conquest in war, sometimes by marriage. It was by the marriage, for example, of three French kings, with two successive heiresses of Brittany where the Salic Law did not obtain, that the Celtic-speaking Duchy of Brittany was united to the French crown and so politically to France.⁷ Slowly but surely, in spite of many checks caused by the English on the one side or the Burgundians on the other, the territorial power of the Capetians grew, until in time, they came to be looked on as kings of France and head of a growing state. More and more the Capetians and their Valois successors absorbed the sovereign power from the feudal barons, whether large or small, about them, until by the time of the peace of Westphalia, the French nation stood out as a clearly cut and fairly harmonious unit.

Within the Germanic Empire by an apparently reverse process the same result was attained. For within the Holy Roman Empire, which Voltaire aptly said was "neither Holy, Roman, nor an Empire," the great feudal vassals of the emperor, instead of having their feudal sovereign rights gradually curtailed and absorbed by merger in the sovereignty of their overlord, the emperor, as happened in France for instance, on the contrary were able to increase their own sovereign rights at the expense of the emperor, until he became a mere shadow which came to an end in 1806 as a result of Na-

⁷ Charles the Eighth and Louis the Twelfth married in succession the Duchess Anne; and François de Valois, who became Francis the First of France, married Claude de France, Duchess of Brittany. The son of this last pair, Henry the Second, became both King of France and Duke of Brittany.

poleon's victorious career. The gradual crumbling away of the Germanic emperor's sovereignty was doubtless due to the fact that he was an elective and not a hereditary prince as was the case with the kings of France and England, for example. As a result within the Germanic Empire there grew up among the welter of small feudal princelings the powerful political units of Hanover, Saxony, Bavaria and Brandenburg, to name only the more important of the developing German states.

Whether in the west, or the center of Europe, however, the importance of relatively small potentates gradually vanished before the rise of the new order of political entities, such as France and England and Brandenburg. As a result, questions began to arise between these more powerful political organisms, while the questions growing out of the relations of individuals to one another fell more into the background with an ever-growing tendency to disappear.

For it was not to the interest of the king or elector or however the supreme overlord of the new order of political organisms might be called, to have their vassals, whether great or small, quarreling and fighting. A continual warfare among the vassals and subjects of the overlord meant an impairment of their sources of revenue and a corresponding loss of power and influence in dealing with their equals about them. And as a consequence the new supreme sovereigns sought by every means in their power to curb the carrying on of private war by their barons. As this war of individuals was gradually suppressed, until to-day in any well-administered state it does not prevail, war began, however, to occur between the newly developing states. As humanity in western and central Europe was delivered gradually of the curse of private war by the growth of the institution of the kingly power, as personified in the royal courts backed up by the police power of the king, there grew up, however, in place of the disappearing strife between individuals, war between the newly forming nations. The rising power of the kings and their like had rescued the European peoples from the continual state of armed peace and war which thrived under the feudal regime. But with the rise of the new nations, for private war there was sub-

stituted war between the new order of sovereigns. Towards the end of the sixteenth century, Gentilis wrote in the "De jure belli": "*Bellum est publicorum armorum iusta contentio.*" Which may be rendered into English, as follows, "War is a just contention of the public force."⁸ And from this same curse of war in a new form the peoples strove to find deliverance.

During the Middle Ages and indeed until fairly recent times, the authors of the various plans, often more or less fantastic, advanced to do away with war and maintain peace between the nations, aimed to accomplish their object by one stroke of statesmanship. Humanity did not realize that changes in the social structure of the peoples can only be accomplished slowly and with the passage of much historic time. While none of the plans to change the world at once into an unarmed camp of peace succeeded, nevertheless, some minor points of difference arising between the new order of sovereigns that emerged from feudalism, as feudalism gradually gave way before nationalism, were referred for settlement to some kind or other form of arbitration. And when the young republic of the New World entered into the membership of the family of nations much impetus was given to the application of international arbitration as a way of settling international difficulties. Still wars occurred to devastate now this, now that land. The eagerness of humanity in the nineteenth century to rid itself of the curse of war and all its accompanying hardships and miseries was abundantly attested by the enthusiasm with which it greeted the official prominence given to mediation, as a means of reconciling rival nations, by the congress of the leading powers of Europe held at Paris in 1856. But as time passed, it was realized that mediation could not blot out war between nations. Then came the trial of the *Alabama* claims before the Geneva Tribunal in 1871-72. That epoch-marking event, coming just after a bitter and costly war between two of the leading powers of the world, gave new hope to a world that dreaded war and all its attending sufferings and evils.

⁸ Alberici Gentilis, I. C. Professoris Regii, "De Ivre Belli, Libri III. Nunc primum in lucem editi. Ad illvstrissimvm Comitem Essexiae, Hanoviae, apud Hæredes Guilielmi Antonii MDCXII.," book one, chapter II., entitled, "Belli definitio," page 17. The above reference is to the third edition. The first edition was published in London in 1598.

And when the Bering Sea Fur Seal case was carried in 1893 to an international court named *ad hoc* for judicial settlement, and that case was followed a few years afterward by the submission, thanks largely to President Cleveland, of the Venezuela-British Guiana boundary to another international tribunal constituted likewise *ad hoc*, the hopes of humanity in the gradual abolition of war rose, and those hopes rose still higher with the assembling at the call of the Emperor Nicholas the Second of the First Hague Peace Conference asking for the limitation of armaments, although that was not a fruit of the labors of the conference.

The more that the subject of peace and war among nations is examined, in the light of past and present events, the more apparent it becomes that new forces must be developed to induce nations to be willing to submit their causes of difference which diplomatic means cannot solve to an international tribunal for solution. The great dread of the loss and suffering brought on by war is sufficient to induce nations in most cases where matters are involved that do not affect their power and strength in the world to agree with their rivals to submit such cases to some sort of international tribunals for decision. But the dread of war is not sufficient to cause nations to agree to seek a judicial solution concerning those questions which do affect the future place and power in the world of nations. In other words in cases of dispute involving the "place in the sun" of nations it is hopeless, where it is uncertain which side is the stronger, to hope for a submission of such cases to international tribunals. International tribunals in their relations to nations have not the compelling power behind them, as municipal courts have in their relations to individuals, to force nations to appear at their bar and abide by their judgments. In the present order of things in the world, nations only take cases to international tribunals which they are willing to submit to such courts; there is as yet no force devised to compel nations to appear before such tribunals as countless numbers of individuals are made to appear almost any day in the municipal courts.

In such questions of difference, as resulted in the Franco-Prussian War of 1870-71, the Russo-Turkish War of 1877-78, the

South African War of 1899-1902, the Russo-Japanese War of 1902-1905, and the present Great War, it would have been useless for any tribunal to have attempted to settle the controversy on the basis of jural rules. The underlying cause of trouble in each of those cases did not involve merely matters which would not affect the future political development and power of the contestants at the council board of the nations of Europe, no matter how the matters in dispute were decided. On the contrary, the cause of strife in each case was because each side wished to possess something which they could not both have, but upon the possession of which, according to the way the question of difference was solved, whether by arms or jural means, the future influence among the members of the family of nations of the rival contestants would be enhanced or lowered.

To build up some sort of international organism which will at all times maintain peace between nations will require much time and effort. Yet something already has been done towards the realization of that object. The machinery necessary to permit judicial settlements to replace wars has been developed. Doubtless it can be perfected still further. But that is not, however, the weak point in the effort, now many centuries old, to maintain peace and avoid the curse of war. The real difficulty is how to induce nations to submit all their differences to some sort or other of international tribunals. Consequently, in order to eliminate war between nations as much as possible, one of the important objects to aim at at present is not so much to try to perfect the judicial machinery for deciding disputes between nations, but rather to do away as much as possible with the things that produce war. In other words, to so change the status of certain relations between nations that the desire to resort to war in order to obtain something will be done away with.

One necessary step to this end of world peace, provided that it is an attainable thing, would be to remove from the world of what may be called some of the hardships that press on certain nations. So far as possible this should be done upon the principle of an equitable *quid pro quo*. An example of that sort of thing was the

world wide territorial rearrangement concluded in 1904 by France and Great Britain. By that arrangement each of those two powers gave up to the other some territory to rectify their frontiers or important privileges in exchange for something elsewhere of equivalent value. In that way the causes of possible clash in the future between them were reduced to a minimum.

In the same way, looking to the present and the future, the United States, for example, could arrange to give Canada one or two, possibly more franc ports along the Alaskan *lisière* in exchange for some other privilege, so that merchandise going into or out of the Dominion would be assured at all times of passage to or from Canada through the Alaskan *lisière* without any vexations or delays arising from our customs.

Or even the United States might give to Canada in exchange for the Island of Campobello, a narrow strip of land leading down to one of the fiords which advance into the *lisière* so that a Canadian railroad could be built to tide water with sufficient space upon the shore to allow a commercial port to be developed.

Another problem which calls in the interest of peace for a wise solution is the need of the great Russian Empire for a port which is never locked up with ice.

It has been suggested that a neutralization of the ocean trade routes of the world would make for the maintenance of peace among the nations. Then, of course, there naturally arises the question how shall that neutralization be maintained? In other words, if the nations agree to neutralize the ocean trade routes, how can that agreement be upheld in times of war?

A rearrangement or reconstruction of the *status quo* between individual nations, however, while helping to make more secure in given cases the peace of nations, would not of itself go very far in eliminating the desire for war between all nations. Something additional is necessary if any serious hope of securing world peace is to be looked for.

One solution of how to maintain peace in the world would be a return to the state of things which did actually occur in the latter part of the period of civilization immediately preceding our own civilization, when the Roman state gained dominion for a consider-

able period of historic time over practically the whole known world, and for that period of time extended the benefits of the *Pax Romana* to the many kinds of peoples living within the frontiers of the empire. The Roman law did much to bring peace to the world. But the *Pax Romana* was extended, it must not be forgotten, by force of arms and was maintained only so long as the Roman legions were able to uphold the power of the empire and prevent the barbarians of the outside unknown world from breaking through the Roman frontiers. And when that force of arms ultimately was no longer sufficient to restrain the rising tide of humanity outside of the empire, the Roman law was swept away with the fabric of the empire and in its place for several centuries chaos reigned.

The conquest of the world, however, by one power as a means of obtaining peace among the nations, is asking all nations, conqueror and conquered alike, to pay a high price. In our own period of civilization persistent efforts have been made to find some other way to do away with the arbitrament of war between nations. And the most generally talked of way in recent years of eradicating war from human affairs seems to be the formation of a world federation. The thought of the formation of a world state superimposed on the present members of the family of nations is not at all a new idea, though some of those who to-day are pressing it forward as the magic wand which will free a suffering world from the dread and cost of future war when the present conflagration has burnt itself out, seem in perfect good faith to believe that it is an idea developed in our own day and generation. That this is not so can be easily seen by any one who will look up what Henry Quatre and the Duc de Sully, Crucé, Penn, the Abbé Saint Pierre, Kant, Lorimer, and other publicists have said on that subject.

As far back as the year 1623, indeed, Émeric Crucé, a Frenchman, propounded in an embryonic form a league to enforce peace by assembling at Venice a congress of ambassadors to sit permanently with the mission of settling cases of difference between sovereigns and with the backing of the combined forces of all the powers represented.⁹ This was really a forerunner of the movement to develop

⁹ Thomas Willing Balch, "Le Nouveau Cynée de Émeric Crucé," Paris, 1623, Philadelphia, 1909, page 101, *et seq.*

an international force to insure peace among the nations which was launched last year here in Philadelphia in our old Pennsylvania State House, only a stone's throw across the square from this hall. That League to Enforce Peace was organized on June 16 and 17 last.¹⁰ The most important object of the league in its purpose to form a league among the nations for the preservation of peace is described in a brief paragraph as follows:

"The signatory powers shall jointly use forthwith both their economic and military forces against any one of their number that goes to war, or commits acts of hostility, against another of the signatories before any question arising shall be submitted" either to an international judicial tribunal or to a council of conciliation.

The idea of the league embodied in the above resolution is not to form a league to make war in order to maintain the peace of nations upon a power not a member of the league, but merely to restrain a member of the league from attacking another member state without first having submitted legal cases of quarrel to an international court or political disputes to a council of mediation. That proposal is a first step, if it can be carried successfully into effect, towards the formation of either a World Federation, or at least a federation of a great part of the world. The difficulties in the way are enormous. Nevertheless, *C'est le premier pas qui coute*, the bishop told the King of Paris when the latter was thinking of adding by conquest to his domain the little town of Saint Denis a few miles to the north of Paris. Perhaps the step taken in the historic Colonial State House of Pennsylvania last June, may possibly be the first step towards the formation of a great international force that will uphold the peace of nations.

As upon the ending of the present Great War, a great deal will possibly be heard of substituting international justice for international war in settling the differences of nations, and indeed already much has been said on that subject in the Americas since the war began, it will be well not to forget the stern realities that the world must face in seeking to accomplish such a beneficent object.

A study of the history of the world, more especially since the

¹⁰ "League to Enforce Peace," printed by the League to Enforce Peace, Fifth Avenue, New York, 1915.

conclusion of the peace of Westphalia and including the course of the present war, would seem to show that while it would be well to do everything possible to avoid war by a recourse to international courts in all possible cases, and much can be done to promote that laudable object, still it is well also to remember that the Creator has ordained our world in such a way that force of some kind, sooner or later, is at the back of all social evolution. You may hold back the laws of nature for a time and even in a way deflect them from their course, but ultimately those laws will prevail and one of those laws of nature is the law of force. And a great and important reason for not forgetting at the present time the realities that the world must face in the effort to do away with war as far as possible, is that just as the Thirty Year's War helped the passing away of feudalism before the incoming new era of nationalism, so it is possible that the Great War will mark a change no less important from nationalism to a new order of things in the world.

It may be said of the questions of disagreement which arise between the members of the family of nations, that, owing to the realization more and more each year by the peoples of the world of the benefits derived from the interplay of commercial interests between nations, as well as the appreciation that war to-day through its great destruction of wealth and life penalizes victors as well as conquerors, there has grown up an invisible, perhaps one might say an intangible force to induce nations to settle most of their legal differences by an appeal to international tribunals. For when international cases can be settled by an appeal to jural rules upon the basis of justice without hurting or endangering the future power in the world of a nation, the peoples have been contented to see their governments invoke international tribunals to decide between the nations. But as yet there has not developed a sufficient force of any sort to induce or compel nations to submit all their political differences to judicial settlement for solution. And so it leaves us face to face with a momentous problem: How will humanity devise a force sufficiently strong to cause nations to settle all their differences without an appeal to war, or in other words, how will the nations transform the present political cases into legal cases?

OBSERVATIONS ON THE MENTALITY OF CHIMPANZEES AND ORANG-UTANS.

By WILLIAM H. FURNESS, 3D., A.B., M.D.

(Read April 13, 1916.)

When in the course of un-human events some years ago in Borneo, I became acquainted with several members of the genus Wild-man that made the island famous, I was possessed with the idea that with constant human companionship and surroundings at an early age, these anthropoid apes—the orang-utan (which of course you know is a Malay name meaning Wild-man or Man of the Jungle)—were capable of being developed to a grade of human understanding perhaps only a step below the level of the most primitive type of human being inhabiting the island—I mean the wandering tribe of Punans. If deaf, dumb and blind children have been taught by beings they could not see to use language they could not hear would one not be justified in an earnest endeavor to teach the higher apes with faculties and senses alert and with traditional powers of imitation, to do the same to a limited degree? It seems well nigh incredible that in animals otherwise so close to us physically there should not be a rudimentary speech center in the brain which only needed development. I have made an earnest endeavor and am still endeavoring, but I cannot say that I am encouraged.

I took as my pupils, or patients, whichever it may please you to consider them, the orang-utan of Borneo and the chimpanzee of Africa. The other anthropoids, the gibbon and the gorilla, are exceedingly difficult to keep in captivity; the gibbon is very frail and the gorilla, animal dealers declare, soon succumbs to homesickness.

My first orang-utan I obtained in February, 1909, in South Borneo, when it was, as well as I could estimate, about one year old; it still had all its milk teeth. It had been in captivity only a week and yet it was as docile as a human baby and never attempted

to bite. It survived four years and eight months. I obtained another orang in 1911, which lived two and a half years in captivity, but although gentle and affectionate it absolutely refused to be educated.

Two chimpanzees, each about a year old, absolutely untrained, I bought from Cross, the animal dealer, in Liverpool in the autumn of 1909. The first one died of pneumonia at the end of five months when her intellect, which showed great promise, was just awakening. The second, which was imported for Dr. Witmer, spent her first months in this country at his laboratory of psychology at the university. After a severe attack of pneumonia she came out to my place to convalesce in company with my orang-utans; she has been with me ever since and is the sole survivor of my four pupils. (I mention these dry facts merely to indicate the material I have worked with, the approximate ages of my pupils and the somewhat limited extent of my experience. Frequently for weeks at a time I have spent as much as six hours a day in their company, but this is not one hundredth part enough.)

In teaching articulate speech I found the first difficulty to be overcome in both the orang and the chimpanzee is their lack of use of lips or tongue in making their natural emotional cries. These natural cries are almost entirely, I think I may say, head tones—shrieks, squeals, or grunts, made for the greater part on inspiration. They unquestionably have, however, distinctly different sounds to indicate their simple emotions of fear, anger and joy. The orang in one respect does use the lips, to make a sound indicating warning or apprehension; this sound is made with the lips pursed up and the air sucked through them—an exaggerated and prolonged kissing sound, followed by a grunting expiration and inspiration. Strange to say, the chimpanzee seems to appreciate on hearing this sound that danger is near, although it never makes this sound itself. When uttering this warning, the hair of the head and shoulders bristles up, but there is no showing of teeth or other signs of aggression. My oldest orang would make this sound on command (I had merely to say "What is the funny sound you make when you are frightened?"). Their expression of pleasure, as I have heard it, is several high-pitched squeaks made with the lips closed. Their ex-

clation of anger is a deep toned guttural grunt or bark much like that of an angry hog; I have heard this from the young orang-utan and from the full-grown just recently captured.

The chimpanzee indication of fear is a quick, high-pitched shriek and a bark very like a dog. The exclamation of joy is really much like laughter. The mouth is opened wide and the sound made is a long drawn ah-a-a, with a rising inflection, this is followed by three or four short, quick Ahs. A sound of greeting and friendliness is a series of *OOs* made by rapid expiration and inspiration, and with lips protruded, merely for the projection of the sound. My chimpanzee when greeting friends at a distance amplifies this sound into more or less of a shout of long-drawn high-pitched notes, which when once started, apparently, must be kept up to a logical conclusion; I have been impelled on many occasions to put my hand over her mouth to subdue the noise but the shout will still continue forced through my fingers while she looks up at me compassionately as one having no ear for melody. Contentment over food seems to be expressed by grunts very much like a young pig.

If these animals have a language it is restricted to a very few sounds of a general emotional signification. Articulate speech they have none and communication with one another is accomplished by vocal sounds to no greater extent than it is by dogs, with a growl, a whine, or a bark. They are, however, capable to a surprising degree of acquiring an understanding of human speech.

In the case of the orang-utan it took at least six months of daily training to teach her to say "Papa." This word was selected not only because it is a very primitive sound, but also because it combined two elements of vocalization to which orang-utans and chimpanzees are, as I have said, unaccustomed, namely: the use of lips and an expired vowel sound. The training consisted of a repetition of the sounds for minutes at a time, while the ape's lips were brought together and opened in imitation of the movements of my lips. I also went through these same maneuvers facing a mirror with her face close to mine that she might see what her lips were to do as well as feel the movement of them. At the end of about six months, one day of her own accord, out of lesson time, she said "Papa" quite distinctly and repeated it on command. Of course, I

praised and petted her enthusiastically; she never forgot it after that and finally recognized it as my name. When asked "Where is Papa?" she would at once point to me or pat me on the shoulder. One warm summer's day I carried her in my arms into a swimming pool; she was alarmed at first but when the water came up to her legs she was panic stricken; she clung with her arms about my neck; kissed me again and again and kept saying "Papa! Papa! Papa!" Of course, I went no further after that pathetic appeal.

The next word I attempted to teach her to say was "cup." (Let me say that by this time she understood almost everything that it was necessary for me to say such as "Open your mouth," "Stick out your tongue," "Do this," etc., and she was perfectly gentle and occasionally seemed quite interested.) The first move in teaching her to say cup was to push her tongue back in her throat as if she were to make the sound "ka." This was done by means of a bone spatula with which I pressed lightly on the center of her tongue. When I saw that she had taken a full breath I placed my finger over her nose to make her try to breathe through her mouth. The spatula was then quickly withdrawn and inevitably she made the sound "ka." All the while facing her I held my mouth open with my tongue in the same position as hers so that her observation, curiosity, and powers of imitation might aid her, and I said *ka* with her emphatically as I released her tongue. After several lessons of, perhaps, fifteen minutes of this sort of training each day she would draw back her tongue to the position even before the spatula had touched it, but she would not say *ka* unless I placed my finger over her nose. The next advance was that she herself placed my finger over her nose and then said *ka* without any use of the spatula; then she found that in default of my finger her own would answer the purpose and I could get her to make this sound any time I asked her to. It was comparatively very easy from this to teach her to say "*kap*" by means of closing her lips with my fingers the instant she said *ka*. At the same time I showed her the cup that she drank out of and I repeated the word several times as I touched it to her lips. After a few lessons when I showed her the cup and asked "What is this?" she would say cup very plainly. Once when ill at night she leaned out of her hammock and said "cup, cup, cup,"

which I naturally understood to mean that she was thirsty and which proved to be the case. I think this showed fairly conclusively that there was a glimmering idea of the connection of the word with the object and with her desire.

By getting her to stick out her tongue and then by holding the tip of it up against her teeth and at the same time forcing her to breathe through her mouth I finally got her to make the sound *Th*. This was preliminary to teaching the words: the, this, that.

All this was encouraging I will admit but then—"I never nursed a dear gazelle . . .," etc.; the poor little animal died four or five months after this first tiny inkling of language. I have tried persistently for five years to teach my surviving chimpanzee pupil to say "mama"; she says it, but very poorly. I think I must honestly say it is a failure. Again and again I have tried by the same method that I used with the orang-utan to teach her to say cup, but to no avail. On the whole I should say that the orang holds out more promise as a conversationalist than does the chimpanzee; it is more patient, less excitable, and seems to take instruction more kindly.

As to a comprehension of the connection of spoken words with objects and actions both the orang-utan and chimpanzee, I think, exceed any of our domestic animals; both of my anthropoids have been able to understand what is said to them, more intelligently than any professionally trained animals I have ever seen. In their education the enticement of food has never been used as an incentive to actions, and praise and petting have been the only rewards. In other words my object has been to endeavor to make them show signs of thought rather than a perfunctory performance of tricks. The very hardest thing that I have had to contend with is inattention and lack of persistence. The slightest sound is enough to divert their minds entirely unless they are deeply interested.

Both the chimpanzee and the orang-utan possess a retentive memory for objects in connection with actions, in other words, for the association of ideas; they knew precisely the right key for every lock and padlock in their apartments and could pick them out of a bunch of ten or twelve other keys and could unfasten the lock. It was the shape and size of the key that they remembered, I am con-

vinced; they were tested with duplicate keys placed on different key rings and the right key was always selected—two of the keys were for Yale locks and hard to distinguish. On one occasion when I took Mimi, the chimpanzee, as a demonstration to one of the classes in psychology at the university she surveyed the audience assembling, possibly 125 men and women, with great interest while sitting quietly in a chair in the amphitheatre; as a group of four or five people entered at a door on the side, she turned her eyes toward them. In the group was one who had been her devoted doctor and nurse during her severe attack of pneumonia four years previously. She had not seen him since her recovery. The instant she caught sight of him she jumped from her chair, rushed to him, threw her arms around his neck, putting her face close to his and giving her shout of greeting. It was too marked a demonstration of affection to be anything short of actual recognition. There are, however, as we all know, many instances of quite as remarkable feats of memory as this among dogs and horses and possibly cats.

After an absence of six months I have found that my apes have forgotten nothing that I have taught them, although during my absence their course of instruction ceased entirely and they refused to do for others what I had taught them. Both the orang-utan and the chimpanzee have been able to learn the letters of the alphabet in order up to *M*. This is merely a demonstration of memory for different shapes in a certain sequence; the letters which I used are cut out of wood $\frac{3}{4}$ inch thick by four inches square. The chimpanzee recollects quite accurately just the sequence of these shapes in the series. By name she does not distinguish them as well, except where the letter sound is very distinct: B, F, H, L, M, seem to be easy for her to recognize whereas A, K, E, D, C, G, are confusing. When asked for the letter *I* she is apt to mistake it for her eye to which she points. When the letters are drawn the same size and width with chalk on a blackboard or printed in black on white cards she fails to recognize them. To test her ability to compare shape and size I have used an ordinary form-board consisting of ten differently shaped blocks about half an inch thick and a board wherein are cut ten hollows corresponding in size and shape to the blocks. The hollows are about $\frac{3}{8}$ inch deep and to make them more easily seen

are painted black inside. The trial consists of placing quickly all the blocks in their corresponding hollows. The actual time required by an adult human being is about twenty seconds. It is strange that with so quick a memory for the shapes of the letters and the keys she should find so much difficulty in mastering the form-board. After hundreds of trials she is never certain to get all ten blocks in place without considerable hesitation and one or two misfits. The more elaborate they are in shape the easier it appears to be for her to place them; the five point star is almost always her first selection from the pile and seldom does she hesitate over it; the equilateral cross is likewise readily placed, but the simple square, the oblong and the lozenge are invariably shifted from one hole to another all over the board. The shortest time in which she has placed them all correctly, so far, is 35 seconds; and the very next trial may have taken $2\frac{1}{2}$ minutes.

I do not wish to generalize, but from my experience with a very bright chimpanzee and an exceptionally receptive orang-utan I should say that the ability to recognize the significance of graphic representation is as lacking in the anthropoid mind as is the inclination to speak. The crudest scrawls of the cave dwellers are hundreds of centuries ahead of the simian thought. I have spent hours trying to get my anthropoids to draw two crossed lines on a black-board. If the board be placed lying flat on the floor in front of them they will draw horizontal lines with the swing of the arm, if the board be placed upright they draw nearly perpendicular lines merely as the weight of the arm carries the chalk down. With pencil and paper they make nothing but scrawling zig-zags with no method in their madness, and no amount of copy set or guiding of their hands will induce them to do otherwise. They have, however, a decided sense of color. Both of them have been taught to know red, blue and yellow by name and the chimpanzee can select and place in separate piles blocks colored violet, blue, green, yellow, orange and red.

In testing their color sense I tried first with a red, a blue and a yellow block and a board whereon were painted squares of the same colors a little larger than the blocks; I showed them over and over again what I wanted them to do and saying the names of the colors

as I placed the blocks on the squares correspondingly colored. Then a block was given to them and they were expected to place it correctly, but it never was done in a way to convince me that they recognized the color. Next they were tested with pieces of ribbon of exactly the same length and width and luster; I endeavored to get them to select and hand to me the color that I asked for. For a month or more I thought that they knew the colors, but to make sure I placed the ribbons in another room and told one of the apes to go and bring me one of the colors, and while she was getting it I kept repeating the name of the color so that she should not forget. This was a complete failure, again and again. They evidently had been reading my expression and the direction of my eyes, when, sitting opposite to them, unconsciously, I followed the direction of their hesitating hands with a glance of approval or disapproval. This was really very observant on their part, but not to the point. They were completely at a loss when I closed my eyes and held out my hand to receive the color that I had asked for.

This did not prove, however, that they could not recognize the different colors; merely that they did not know them by name. The next trial therefore was with 24 blocks, 8 red, 8 blue, 8 yellow; all scattered over the table. One color was called for by name and if that was selected rightly then all the others of that color must be picked out and placed in my hand. I would never accept a wrong color, but would either close my hand or snap it out of their fingers; the lesson would not stop until all the eight blocks of each color had been rightly selected, so they gradually learned that a quick selection of right colors meant a speedy release to play. In this manner also they learned the names of the colors as applied to blocks, but if other red, blue and yellow objects such as ribbons were placed among the blocks I could never get the apes to consider them in the same category as the blocks merely because they were of the same color. When the chimpanzee knew the three colors distinctly both by name and by sight a new set of twenty-four was given to her, but this time there were four each of violet, blue, green, yellow, orange and red. It was decidedly unexpected to find that she readily appreciated the difference of these new tints and at the end of the first lesson was able to build up all the blocks in separate colors, although the tone

of coloring of the green and the blue, and the yellow and the orange were very much the same. My chimpanzee, at least, has an appreciation of color distinct from tone.

Actions which on first thought would seem to require almost human intelligence such as stringing beads, threading a needle, using a spoon, or a fork, drinking out of a cup, washing the hands, etc., our anthropoid cousins seem to accomplish with great facility. Possibly these are but slight modifications of instinctive actions of use in the pursuit of food, or to satisfy a natural curiosity. A twig or a stick may be poked into a hole to pry out a grub or the kernel of a nut, a drink of water out of the hollow of a leaf is like drinking from a cup; sticky juice of fruit on their hands they naturally find may be counteracted by a good rubbing in sand or water, therefore, I do not think that such actions demonstrate any marked degree of mentality. But tying a knot in which three or four different motions were required and where no object other than the formation of a knot was attained, required long and persistent instruction. The knot was tied hundreds of times while the ape was apparently closely observing every action and then her hands were put through the motions but yet she would only twist one end of the rope round the other when left to herself. Simple actions such as digging with a spade, or trowel, scrubbing, sweeping, screwing in a screw she learned entirely by imitation.

I am eager to be able to say truthfully that my anthropoids have showed signs of reasoning (I mean have deduced an inference from certain premises), but truthfully I can say that I have seen only the faintest rays of evidence, unless association of ideas which in point of fact is merely learning by experience, is reasoning. The chimpanzee if given the key to the closet in her room will fit it in the lock, turn it in the right direction, slip back the little spring catch, open the door, get the top of the spigot which is kept there to avoid a waste of water, fit the top of the spigot, get a drink of water and finally turn the water off. It appears as if in this act there were a sequence of ideas concerted to accomplish a purpose and therefore to a certain extent there were reasoning. I am inclined to think, however, that such an act with the chimpanzee is governed by a simple succession of ideas rather than by a pre-arranged sequence

of actions, with a definite object in view. It would seem that the inability to compare one object with another or one action with another precludes their mind from either deductive or inductive reasoning, and that their brains are as incapable of reasoning as we do, as a dog's paw (for instance) is incapable of holding a pen as we do. They undoubtedly can be taught, owing to their physical resemblance, to imitate human actions to a remarkable degree, but their highest notch of mentality after four or five years of training is hardly comparable to that of a human child of a year and a half. Rev. Sydney Smith in the introduction to one of his lectures on moral philosophy says:

"There may, perhaps, be more of rashness and ill-fated security in my opinion, than of magnanimity or liberality; but I confess I feel myself so much at my ease about the superiority of mankind—I have such a marked and decided contempt for the understanding of every baboon I have yet seen—I feel so sure that the blue ape without a tail will never rival us in poetry, painting and music—that I see no reason whatever, why justice may not be done to the few fragments of soul and tatters of understanding which they may really possess. I have sometimes, perhaps, felt a little uneasy at Exeter 'Change from contrasting the monkeys with the 'prentice boys who are teasing them; but a few pages of Locke, or a few lines of Milton, have always restored me to tranquility."

I regret that I am forced to admit, after my several years observation of the anthropoid apes, that I can produce no evidence that might disturb the tranquil sleep of the reverend gentleman.

WALLINGFORD, PA.,
April, 1916.

SYMPOSIUM ON INTERNATIONAL LAW: ITS ORIGIN, OBLIGATION, AND FUTURE.

(Read April 15, 1916.)

I.

OUTLINE.

By JOHN BASSETT MOORE, LL.D.

I. ORIGIN.—International law, like all other kinds of law, originated in the necessities of intercourse between human beings. Just as rules developed for the regulation of life within individual groups, so, as groups became permanent and were transformed into states, rules developed for the regulation of their intercourse with one another. The system thus gradually formed was not artificial in any sense other than that in which all legal systems are artificial. Regulation is just as essential to the relations between groups of men as it is to the relations between individual men.

In spite of the fact that it was formerly the fashion of writers to say that the law of nations, or international law, was altogether of modern origin, the recent researches of scholars have tended more and more to disclose the existence of well-defined rules for the regulation of international intercourse among the ancients. There existed, for example, among the Greeks and the Romans, a large body of customary law governing their intercourse with aliens and with alien states. Among the Greek states themselves, there was a large body of usages in accordance with which their relations were conducted. The judicial settlement of disputes between them, by means of arbitration, was carried to a very high point and was attended with a large measure of success. Within the past twenty years, much light has been thrown on this subject by the study of inscriptions, which has conclusively demonstrated as clear and precise an application of the judicial method to the settlement of dis-

putes between the independent Greek states, as has been made to the settlement of disputes between nations in recent times.

These things I particularize for the purpose of emphasizing the point that all law, so called, whether national or international, grows out of the necessities of human intercourse. We commit a fundamental error in thinking of any system of law as an artificial creation.

II. OBLIGATION.—It was altogether in harmony with the view above expressed that Grotius and other so-called founders of the modern system of international law regarded its acceptance as a fundamental condition of the admission of a state to its benefits. By these writers the system was regarded as having had its origin among the Christian states of Europe, and non-Christian states were admitted to its benefits only to a limited extent. In course of time, this conception ceased to be sufficiently comprehensive. By the Treaty of Paris of 1856, Turkey was expressly declared to be admitted to the benefits of the public law and concert of Europe. Subsequently, certain states of the Far East, beginning with Japan, expressly assented to the system and were duly recognized as participants in it.

But, so far as obligation is concerned, it matters not whether the system was tacitly accepted or expressly adopted. In both cases, the obligation is the same.

It is necessary, however, to observe the distinction between obligation and enforcement—between the duty to observe a certain rule and the power to compel its observance. The failure to make this distinction constantly produces confusion. We know, as a matter of fact, that, in the attempts to enforce municipal law, a failure of justice often takes place. The skill of an attorney or the bias of a juror may, and no doubt often does, result in the acquittal of a guilty defendant, and yet it does not occur to anyone to say that, because the defendant thus escaped the punishment which he should have been obliged to undergo, the duty of obedience to the law did not in his case exist. Such a suggestion we should regard as absurd. Nevertheless, we daily hear the allegation that there is no such thing as international law, because, forsooth, some nation has violated, or is said to have violated, an acknowledged rule.

There is as little reason for the assertion in the one case as in the other.

III. THE FUTURE.—Since the great conflict in Europe began, the days have perhaps been rare on which the teacher or student of international law has not been greeted with the profound remark that there is no such thing as international law, or that international law has come to an end. As there are comparatively few persons who have deeply studied international law, it should not seem to be ungracious to say that such remarks betray a want of information, or at any rate of reflection. The rules of international law are by no means so indefinite or uncertain as they are often supposed to be, or as interested persons often seek to make them appear to be; nor is their observance by any means so casual as is sometimes imagined. It would be difficult to find in international law an example of uncertainty greater than that which attended the interpretation and enforcement of the so-called Sherman Anti-Trust Law, which, after twenty years of strenuous controversy, was left to be interpreted according to the "rule of reason." Nor is international law in ordinary times badly observed. It is, in fact, usually well enforced; and any differences in regard to its interpretation and enforcement are, except in matters of a political nature, commonly left to international tribunals for determination, in connection with individual claims.

The present misconception in regard to international law is largely due to the tacit but unfounded assumption that municipal law is well enforced in time of war. Precisely the contrary is the fact. There is indeed an ancient maxim of the common law, to the effect that in the midst of arms the laws are silent—*Inter arma silent leges*. This maxim was not a creation of the fancy, but was merely an expression of the results of experience. Law never has been and never will be found in a flourishing condition between firing lines. War itself means that the reign of law has been superseded by a contention by force. During war the ordinary law is constantly superseded by martial law, which has been defined as the "will of the commander-in-chief"; and while this does not mean an unregulated will, or mere caprice, it does signify the supplanting of the system by which rights are ordinarily regulated and enforced.

The fact is not today generally appreciated that the fundamental guarantees of personal liberty were set aside in the United States during the Civil War, and that the people lived under a military dictatorship. A benevolent dictatorship it may have been and no doubt generally was, but it was nevertheless a dictatorship. When, soon after the outbreak of the war, a citizen of the state of Maryland, which had not seceded from the Union, sought to avail himself of the writ of habeas corpus, the marshal of the court who sought to serve the writ was informed by the military officer who held the prisoner in custody that he took his orders not from the courts but from the War Department at Washington. The meaning of this was that the constitutional guarantees of personal liberty were suspended; and grave statesmen went so far as to announce that they approved the course of the administration just in proportion as it disregarded the law. There were many persons at the time who thought that the constitution of the United States had come to an end, just as many persons are now saying that international law has come to an end. The difficulty with such persons is that they look for law between firing lines, and regard a temporary phase as a permanent condition.

I do not hesitate to affirm that the violations of international law during the present conflict in Europe, fierce and wide extended as it is, have not exceeded, either in number or in importance, those that occurred during the wars growing out of the French Revolution and the succeeding Napoleonic Wars. In reality, many recent violations, which are commonly supposed to be new, have precise precedents or analogies in what took place in the former titanic struggle, in which there were extensions of the contraband list and interferences with commerce under pretences of blockade, just as there have been during the present great struggle. These things are done, not because of any uncertainty as to the law, but because the parties to the war, being engaged in a life and death contention by force, naturally think more of their own safety than of the interests of neutral nations.

Nor is there in these things any reason for discouragement as to the future of international law. As the ordinary rules of intercourse have in all previous conflicts been more or less disregarded,

according to the exigency or the intensity of pressure, so it has been found that, when the incidents of the struggle came to be surveyed, there arose a general desire to extend the domain of law, to define its rules more clearly, and to take measures for their more effectual enforcement. This was what happened after the Thirty Years' War. The same thing occurred after the close of the wars growing out of the Spanish Succession. It happened again after the close of the Napoleonic Wars; and a similar phenomenon distinguished the ending of the Crimean War. Many of the mournful lucubrations regarding violations of international law in the present war have, consciously or unconsciously, a partisan character, and are intended to further the interests of the one side or the other. We should be on our guard against such lamentations. They are by no means new in character; they are characteristic of all wars. All armed contests are characterized by charges and countercharges of violations of law, and such charges are partly false and partly true. There never took place, and never will take place, a contention by force in which the so-called rules of war were not violated. War itself means the killing and maiming of human beings, and, in the passions it excites and the fears it creates, excesses will inevitably be committed. It is in the nature of things that it should be so.

Judging, therefore, by the past, we are justified in looking forward to important developments in international law after the present great conflict shall have been ended. These developments will naturally take place along the ordinary lines of legal progress. In the first place, there will always be differences to be settled. This is a matter of primary importance, since it involves the avoidance of conflict and the preservation of peaceful conditions of legal growth. We may call this the judicial aspect, which has been dealt with chiefly through international arbitration.

But, in the second place, while law must be interpreted, it must also be progressive, and must keep pace with changes in conditions. The greater part of international law has been developed through usage, but, during the past hundred years, it has undergone a marked development through acts which were in their nature legislative. To what extent is it possible to enlarge and render more efficient the legislative method in the international sphere? Up to the present time,

the chief obstacle has been the requirement of unanimity. Acts which seemed to be beneficent have been blocked because two or three powers, or perhaps one power, refused to assent to them.

In the third place, we have the administrative aspect of the system. Is it possible to develop anything in the nature of an international administration? We know that in certain matters, such as that of the posts and the telegraph, marked progress has been made in that direction. The great difficulty arises when we come to deal with things of a contentious nature. We have heard a great deal of "international police." An examination of what has been said on the subject must be admitted often to betray an exceedingly slight comprehension of fundamental conditions. So far as the phrase "international police" implies the use of force, it involves the most serious of all problems with which the student of international affairs and the statesman can be confronted. The use of force effectively is a matter that readily assumes immense proportions; the use of force ineffectively may readily create a condition of anarchy.

Lastly, we are brought to the consideration of the question as to whether and to what extent it is possible, by means of organization, to secure the more effective development, interpretation and enforcement of international law. It is not a new question, but it is a very serious and difficult one. Europe has been trying for hundreds of years to find a solution of it, but has not yet succeeded. The mere association of nations, as they now exist, in an alliance or league, with a view to bring force to bear upon a recalcitrant nation as readily as it can be applied to a recalcitrant individual in a municipality, would of itself afford little assurance either of effectiveness or of permanency. The difficulties are too complex to be solved by any single agency.

COLUMBIA UNIVERSITY,
April, 1916.

II.

THE JUDICIAL ASPECT OF INTERNATIONAL LAW.—
ARBITRATION.

BY CHARLEMAGNE TOWER, A.B., LL.D.

Whilst the principles of international law have been enlarging their influence and developing, in their application to the great variety of questions which have arisen from time to time out of the advance of civilization during the past hundred years, and their authority has been continuously extended as the result of a wider recognition throughout the world, by mutual agreement, of the rights of one people, in its international and sovereign capacity, toward another people, no means of promoting harmony has been discovered which has proved to be so efficient as the recourse to arbitration in the settlement of international disputes.

The employment of it in the nineteenth century increased at certain periods with such rapidity that it has been shown by a comparative statement to have doubled in the number of cases in each period of ten years in comparison with that of the same length of time immediately preceding it; and if we were to enumerate the nations which have submitted their disagreements to its adjustment we should include not only the United States but the great Powers of Europe as well—Great Britain, France, Austria-Hungary, Italy, Germany and Russia, as also almost every country in the world—for instance, we should have, besides Spain, Denmark, Belgium, Holland, Norway and Sweden—Turkey, Greece, Persia, China, Japan, Mexico and all the republics of Central and South America.

Statesmen of all the cabinets of the world have turned to this method of arriving at conclusions which shall safeguard national honor and content public opinion on both sides of a controversy, without a breach of international relations and without recourse to the force of arms.

We must admit, unhappily, from the evidence that is forced upon us by the spectacle of the great conflict now going on amongst the

nations of Europe, that arbitration has not been able always to prevent war; that, even with its conciliatory processes of mediation and intervention, it has been swept aside by war; that nothing has been devised which, in the present attitude of the peoples of the earth in their relations to each other, and in the existing conditions of the human mind, can abolish war. But, just as international law itself if forced beyond a given point is found to have its limitations, so its component parts, of which arbitration is one, can not be expected to attain to that which no human agency has as yet made possible.

That it is a method of avoiding conflict and preserving peace, there can be no possible doubt; nor can we fail to admit its efficacy when we consider how frequently heretofore it has intervened amidst the passions of men, and how, even in our own case, when the interests and temper of the people were drawing them to the verge of a conflict it has turned aside from us the frightful disaster of a modern war.

It may be said, indeed, with honor to the generous purposes of the American people in their public dealings with other nations, that this principle of fair and just consideration of the claims of right on both sides has been taken as the basis upon which they have rested their contentions in the international controversies that have presented themselves, ever since the establishment of the independence of the United States.

It appears in the plan for the adjustment of the differences subsisting between ourselves and Great Britain immediately after the Revolutionary War, and for the establishment of our boundary lines along the River St. Croix mentioned in the treaty of peace; and we see it in the provision made by Mr. Jay's treaty, to that end, in 1794, that the disputed questions should be referred to the final decision of commissioners, one of whom is to be appointed by the King of Great Britain, one by the President of the United States, by and with the advice and consent of the Senate, and these two commissioners are to agree upon the choice of a third; or, if they can not so agree, they shall each propose one person, and of the two names so proposed one shall be drawn by lot in the presence of the two original commissioners. The three commissioners so appointed shall be sworn impartially to examine and decide the said question, ac-

cording to such evidence as shall respectively be laid before them on the part of the British government and of the United States.

We have here the principles of arbitral adjustment fully developed at the outset, and we have employed it repeatedly in the same manner through an exceedingly interesting and important series of negotiations by which not only the St. Croix dispute was adjusted, but the whole boundary line along our northern frontier has been established, from the Atlantic ocean to the Pacific; the northeastern boundary by Mr. Webster and Lord Ashburton in 1842,—the line from the Great Lakes to the Rocky Mountains, and from thence to the ocean. So that when the San Juan water boundary was finally determined by the decision of the German Emperor, as arbitrator, in 1872, General Grant was able to report to Congress in his annual message, in December of that year, that:

"This award confirms the United States in their claim to the important islands lying between the Continent and Vancouver's Island, . . . and leaves us, for the first time in the history of the United States as a nation, without a question of disputed boundary between our territory and the possessions of Great Britain on this continent."

The success of this kind of negotiation, and perhaps a growing habit of thought which resulted from it and attached itself to it, very naturally increased the value, as it also extended the influence upon men's minds, of the advantages to everybody concerned, that is to be gained through the amicable adjustment of international disputes where that course is possible. Thus it came to be generally accepted, that arbitration is the most direct and effective method of settling such controversies, especially in cases where actual national integrity or national honor is not at stake; and the immediate effect of this was made evident by the greatly increased ratio of arbitral adjustment, already noted, in the course of the nineteenth century, in which substantially all the nations of the world have taken part.

The high point was reached, however, one may safely say, in considering all the circumstances, that the greatest political and moral result that the world had ever seen to come out of an international settlement was attained by the Geneva Tribunal in its composure of the difficulties then existing between the United States and Great Britain which had arisen out of the *Alabama* claims, both on account

of the extremely grave situation in which the two nations found themselves, the delicacy of the relations involved which touched the national pride of each in a manner quite capable of producing acts of hostility at any moment, and the importance of the questions of right and of injury which were actually at issue as the cause of the dispute. In some respects also the ground was new; and this was an untraveled road which seemed at the time to be quite impossible of approach, even after the inducements held out by the United States government. Mr. Adams announced, in fact, in his note to the British Foreign office that he was: "directed to say that there is no fair and equitable form of conventional arbitrament to which the United States would not be willing to submit."

But, even after the lapse of two years, Lord Russell's mind was still so completely in revolt against the idea that it could be possible for Great Britain to entrust to the decision of a foreign power such a delicate question of national responsibility, that he declared abruptly:

"It appears to her Majesty's government that there are but two questions by which the claim of compensation could be tested; the one is: Have the British government acted with due diligence, in good faith and honesty, in the maintenance of the neutrality they proclaimed? The other is: Have the law officers of the Crown properly understood the foreign enlistment act, when they declined, in June, 1862, to advise the detention and seizure of the *Alabama*?

"Neither of these questions could be put to a foreign government with any regard to the dignity and character of the British Crown and the British nation. Her Majesty's government are the sole guardians of their own honor. They cannot admit that they have acted with bad faith in maintaining the neutrality they professed. The law officers of the Crown must be held to be better interpreters of a British statute than any foreign government can be presumed to be. Her Majesty's government must decline to make reparation and compensation for the captures made by the *Alabama*."

On our side, in the meantime, Mr. Seward reflected, in his instructions to Mr. Adams, the intensely strong national feeling and the determination of the whole American people, when he declared that there was not a member of the government nor, so far as he knew, any citizen of the United States who expected that this country would in any case waive its demand upon the British government for the redress of wrongs committed in violation of international

law; "the massive grievance," as Mr. Sumner said, "under which the country had suffered for years, and the painful sense of wrong planted in the national heart."

It must be looked upon as the triumph of international forbearance and of the willingness upon the part of the two nations to compose amicably their differences, which turned aside the menace and reëstablished peaceful relations at the moment when we were upon the brink of war. Its influence and its lasting moral effect were unquestionably greater, not only as between ourselves and Great Britain but also in their direct bearing upon all the Powers of the world, than could probably have been produced by any result obtainable through the arbitrament of war. The most remarkable instance in this connection is perhaps the agreement reached in regard to the famous "Three Rules" of the Treaty of Washington relating to the "due diligence" that a neutral government is bound to employ in preventing belligerent cruisers from arming and equipping or from departing from its waters, which was the basis of the American case relating to the *Alabama* claims. For the British commissioners were finally instructed to declare that they could not assent to those rules as a statement of principles of international law in force at the time when the *Alabama* claims arose, but that

"Her Majesty's government, in order to evince its desire of strengthening the friendly relations between the two countries and of making satisfactory provision for the future, agreed that in deciding the questions between the two countries arising out of those claims, the arbitrator should assume that her Majesty's government had undertaken to act upon the principles set forth in the rules in question."

Thus it was possible to employ the method of arbitration in order to prepare a common meeting-ground upon which the nations could approach each other as equals, and treat without prejudice—each recognizing the right of the other to present its claims as they appeared from its own national point of view, and to seek justice.

Probably nothing of the kind had ever influenced the world like it before; and it marks a stage of progress from which the world can never recede; for arbitration is a growth which in the affairs of men indicates the advancing steps of civilization.

We have, of course, as the great example and proof of this, the

conferences at the Hague, to which the nations went in 1899 and 1907, ready to make concessions each of its own personal interests in the effort to attain to results beneficial to all.

Whilst the reduction of the heavy burden of the armaments then resting upon the peoples of Europe was the motive of the Emperor of Russia in calling the First Conference together, and whilst the Conference did not find itself able even to bring that subject to serious consideration by the Powers, it reached definite results in other directions which must be regarded as very remarkable steps forward in the progress of mankind.

With its memorable declaration that, "in order to obviate as much as possible the recourse to force in the relations between states, the contracting Powers agree to use their best efforts to insure the pacific settlement of international disputes;" and "for the purpose of facilitating immediate recourse to arbitration in cases which have not yielded to diplomatic effort," the conference established a permanent court, accessible at all times and competent for all arbitral questions, as a world tribunal before which nations may appear as litigants and have their cases heard.

The Conference of 1907 enlarged the field of peaceful endeavor still further by providing for more extended efforts toward arbitral adjustment through the good offices and mediation of other Powers; so that,

"in case of serious disagreement or dispute, before an appeal to arms, the Powers agree to have recourse, as far as circumstances will permit, to the good offices or mediation of one or more friendly Powers. And, independently of this recourse, the contracting Powers deem it expedient and desirable that one or more Powers, strangers to the dispute, should, on their own initiative and as far as circumstances may allow, proffer their good offices or mediation to the states in conflict;"

a very great variance from the older customs of Europe which is of especial importance because of the concessions which it implies. For, in the extreme sensitiveness of national honor and the jealously guarded distinction of national personality, a war was looked upon formerly as a subject that related solely to the belligerents engaged and their friends and allies, in which no one would venture to interfere who was not interested in it, any more than one would inter-

fere with the participants and their respective seconds in a duel, expecting not to be considered impertinent or not to give offence.

But the Conference agreed, and this marks the enlargement of human thought, that Powers which are strangers to the dispute may take the initiative, that they shall have the right to offer their good offices or mediation, even during the course of hostilities; and that the exercise of this right can never be regarded by either of the parties in dispute as an unfriendly act.

The part of the mediator consists in reconciling the opposing claims and appeasing the feelings of resentment which may have arisen between the states at variance.

The judicial element of international law has thus become, in a sense, the paramount influence in the establishment and adjustment of international relations. It is this which will direct the course of such relations in the future; and upon it will be largely built up the international law of the future. The Conferences at the Hague have erected a new and substantial fabric; so that we have now, provided by its court of arbitration, a tribunal of recognized competence and fixed rules of procedure, open to all; whilst the contracting Powers formally agreed, at its inception, that the award of the court of arbitration, duly pronounced, "puts an end to the dispute definitely and without appeal."

Our own government entered during Mr. Roosevelt's administration, whilst Mr. Root was Secretary of State, into separate conventions with several of the great European Powers, Great Britain, for instance, France, Spain, Russia, and with the republics of South America, which provide, under regulations agreed to at the Hague, that

"Differences which may arise of a legal nature, or relating to the interpretation of treaties existing between the two contracting parties, and which it may not have been possible to settle by diplomacy, shall be referred to the permanent court of arbitration, provided that they do not affect the vital interests, the independence, or the honor of the two contracting states, and do not concern the interests of third parties.

"In each individual case, however, before appealing to the permanent court, the contracting parties shall conclude a special agreement defining the matter in dispute, the scope of the powers of the arbitrators and the periods to be fixed for the formation of the arbitral tribunal and the several stages of the procedure. Each of these special agreements must be made, however,

under the terms of these treaties, by the President of the United States with the advice and consent of the Senate."

It is interesting to note that, from the point of view of the foreign relations with the peoples of other countries, the government of the United States has taken part in proceedings in arbitration, where awards have been made by the arbitrators, in 83 cases altogether; for example, with France 2, with Russia 1, with Spain 6, with Great Britain 17, with Germany 1, with China 3, with Brazil 3, etc., and the results of these different settlements are very well worth notice also in this connection; for, the aggregate of all these awards is \$92,855,000.00, of which about sixty-nine millions were in our favor, and about twenty-four millions against us. So that, taken altogether, nearly 75 per cent. of all the awards have been made in favor of the claims of the United States government, and 25 per cent. opposed to them.

So much for arbitration in the past. If we look forward the future presents many problems to the statesmen and judges and lawyers of all the Powers, which will have to be met by them when order has been restored once more and men resume the habits of civilized life after this period of conflict which we are now passing through. The world requires order and tranquillity as the conditions under which civilization may continue to progress. After all the sacrifice, and all the terrible suffering and distress entailed by this armed conflict, in spite of the courage and devotion and patriotism so freely shown on every side, the one prominent intellectual gain that we and all men hope to see as the result, will be the conviction of the futility of war, and renewed confidence in the precepts of international law. The rules of adjustment and forbearance and concession which led the nations to the Hague, must be restored and must point the way again during our generation, let us hope, and for beyond our day, to international well-being through the aid of law and justice and arbitration of disputes, with mutual respect, toward the peace of the world.

PHILADELPHIA,
April, 1916.

III

LEGISLATIVE ASPECTS.

By GEORGE GRAFTON WILSON, A.M., PH.D., LL.D.

It is peculiarly fitting that the legislative aspects of international law should be presented before a philosophical society. In true international law there must be some classes of rights which may from their nature be regarded as resting upon philosophical bases. Certain laws are recognized as binding among states because they appeal to mankind as having a sound foundation in human reason. International law so far as resting on such ideas as sovereignty and equality of states must find support in philosophical concepts. Similarly, in international legislation a view that may be called philosophical must be taken.

The early writers often sought a philosophical basis in the law of nature which might be discovered in the dictates of right reasoning, dictates not to be arbitrarily set aside even by deity which had created the reasoning faculty. Thinkers have realized that international law must make an appeal to the mind of mankind rather than to that of men of a single type. From the very nature of the law as international it must receive the approval of representatives of states differing widely in fundamental ideals and national policies.

The nature of the state, which is the person in international law, determines the scope of the law and the range of international legislation. The state being a political entity responds and must respond to stimuli which are political. There is then involved in international legislation the question as to what is for the public well-being in contradiction at times with what may be for the well-being of a given individual or group of individuals. The degree to which different states will consider the well-being of individuals within the state will again be a political question determined by the degree of participation which the individual may have in state affairs. Accordingly when international law is formulated with view to application to a few homogeneous states, its range may be

wide because the consensus will be large, while attempts to reach an agreement among many heterogeneous states will result in the lessening of the range of possible legislation. This is strikingly evident in such an attempt as that in private international law, so-called, where the proposition to unify the laws of marriage and divorce has been made. An attempt which has not met with complete success even among the reasonably homogeneous states of the United States could hardly be successful among the nations.

The representatives in power among the states of the world are usually desirous of retaining the positions which they may for the time be occupying. They therefore usually give heed to what seems to be the will of the state. The state being a political entity seeks what it regards as advantageous to itself. This was particularly true when all foreigners were regarded as barbarians or as enemies, and the idea still is very potent. Indeed there are few states even now which would sacrifice themselves for the good of the world at large, and their representatives are governed accordingly. While the utility theory may have disappeared in some fields of thought, it has not disappeared in international affairs. Bentham's influence is not merely evident in the name international law, but also in many of its foundations.

If, then, international legislation must largely rest upon the recognition of advantages to be gained or to be hoped for and if the interests of states are in fact or supposedly antagonistic, this legislation will be limited in scope. On the other hand, in so far as states can be shown that their interests are common and that action or restriction of action is of advantage to all, the scope of international legislation will be extended. Presumably the well-being of a modern state would be closely bound with the well-being of its citizens whether this be embodied in the formula "life, liberty, and the pursuit of happiness" or in other words.

Legislation usually refers not to the general idea of right and justice but to what is enacted as in the idea of *lex, loi Gesetz*. Accordingly the legislative aspects of international law are somewhat strictly limited. If then international legislation be considered merely as that body of principles formulated by agreement among states, the application of the above propositions is evident.

The destruction of life without advantage to any state was one of the first matters to receive attention as a subject for a formulated international agreement. This proposition that a state should not take or sacrifice lives of men without commensurate advantage would seem almost self evident. Yet the first international agreement relating to this matter to receive general assent was concluded in 1864, and known as the Geneva Convention for the Amelioration of the Condition of Wounded in Armies in the Field. The representatives of twelve European states stated in the preamble their purpose to be to mitigate "the evils inseparable from war, to suppress useless severities, and to ameliorate the condition of soldiers wounded on the field of battle." It would seem a long time for the world to wait for such legislation. This Geneva Convention of 1864, which provided for the immunity of the hospital corps, was not immediately ratified, however. The United States did not adhere to this Convention till 1882, and this was the only international agreement of general scope and relating to war to which even the United States became a party before the end of the nineteenth century, a fact seeming to indicate that there is difficulty in international legislation.

In regard to property there had been propositions and formal declarations which had become embodied in law. The Declaration of Paris of 1856 received the approval of many states, and by this Declaration (1) privateering was prohibited; (2) neutral goods and enemy goods under a neutral flag were protected; and (3) paper and ineffective blockades were discouraged, but the United States did not adhere to this Declaration, though announcing in the Spanish American war in 1898 that it proposed to observe the principles of the Declaration.

Other matters became increasingly the subject of international legislation, and before the end of the nineteenth century, general conventional agreements had been made and signed by a large number of states acting together upon such matters as an "International Bureau of Weights and Measures" (Metric System), 1875; "International Protection of Industrial Property," 1883; "Protection of Submarine Cables" (in time of peace), 1884; "Exchange of Official Documents, Scientific and Literary Publications," 1886; "Repression of African

Slave Trade," 1890; "Formation of an International Union for the Publication of Customs Tariff," 1890; and "Regulation of Importation of Spirituous Liquors into Certain Regions of Africa," 1899. Such international agreements became a part of the written law of nations, but covered only a very small part of the entire field of international relations in peace and war.

Toward the end of the nineteenth century there was developing an idea that there should be a wider common agreement among the states of the world upon matters of common interest and that the will of these states should be formulated in conventions. Plainly, if the nations of the world constituted a family the rules of action for its members might be stated. The family idea had been advanced as the basis for international relations and the membership in the family had gradually enlarged. It was coming to be believed that the nations had sufficient unity of interest and willingness to act together to enlarge the scope of international agreement. This was in a somewhat comprehensive way put to the test in 1899.

While the United States and Spain were still at war, at the diplomatic reception of August 12, 1898, at St. Petersburg, Count Mouravieff, Russian imperial minister of foreign affairs, delivered to the representatives of the Powers a communication from His Majesty the Czar. The nature of the document gave rise to surprise, but its character and source demanded immediate attention. Mentioning the competition in development of means of international combat and the effect of this competition upon the states of the world, he proposed an international conference, saying that

"To put an end to these increasing armaments, and to find means for avoiding the calamities which menace the entire world, that is the supreme duty which lies upon all nations."

The United States replied that

"Though war with Spain renders it impracticable for us to consider the present reduction of our armaments, which even now are doubtless far below the measure which principal European powers would be willing to adopt, the President cordially concurs in the spirit of the proposal of His Imperial Majesty."

Another circular was presented to the Powers on January 11, 1899, containing a tentative program. This program suggested

agreement upon (1) limitation of armaments; (2) restrictions upon new methods of warfare; (3) prohibition of firing from balloons; (4) prohibition of submarines and rams; (5) adaptation of principles of Geneva Convention of 1864 to naval warfare; (6) neutralization for vessels saving those overboard after battles at sea; (7) revision of rules of war on land; and (8) acceptance of principles of mediation and arbitration with view to preventing armed conflicts.

It will be observed that of these eight topics suggested, seven look to furthering peace by limitations upon the conduct of war, and the last topic suggests a quasi-legal method of furthering the movement toward peace.

The international conference suggested by the Czar and representing twenty-six Powers met on the 20th of May, 1899, in the House in the Woods in the quaintly beautiful Dutch city, The Hague, and remained in session a little more than two months. It is known as the First Hague Peace Conference. The Conference drew up three conventions, three declarations, one resolution, and six wishes: Conventions (1) for the pacific settlement of international disputes by means of good offices and mediation, commissions of inquiry and arbitration; (2) regarding the laws and customs of war on land; (3) adaptation of Geneva Convention of 1864 to maritime warfare; Declarations (1) prohibiting the discharge of projectiles from balloons; (2) the use of projectiles for the diffusion of deleterious or asphyxiating gases; (3) the use of expanding bullets; Resolution-affirming the desirability of the restriction of military budgets; Wishes for further consideration of various matters upon which the Conference had not reached agreement. The last topic upon the program suggested by the Czar, had become the first Convention of the First Hague Conference, or the furtherance of the aim of peace by means quasi-legal in character assumed a foremost place in the results of these deliberations at The Hague; and the first item in the program, the attainment of international peace through the restriction of the means by which each nation had hitherto maintained its rights, viz: effective armament, became the subject of a resolution and a wish. The last had become first. The Conference had asserted its confidence in the law as the method for settling international disputes.

While many cast ridicule upon the results of this First Conference at The Hague, states, however, gradually adopted the Conventions drawn up in 1899, and a law for nations deliberately drawn by the representatives of the states assembled for that purpose became a fact.

There followed eight years later a Second Hague Conference which further elaborated and formulated conventional agreements, and to this conference representatives of forty four of the states of the world came, giving ample evidence of the tendency to accept the principle of international legislation. Some of the conventional agreements have been tested in the course of years. The court established for the settlement of international disputes has attained a recognized standing. Cases affecting all parts of the world and more than one third of the nations of the world have already been decided. Many principles have been involved. The awards accepted unhesitatingly have tested the strength of the law.

The Second Hague Conference, building upon the legislation already formulated, endeavored to extend its scope. Among the propositions which have not been adopted as yet into the law of nations was that to establish an international prize court. This proposition was generally approved in principle though a satisfactory method of selection of judges was not devised. To supplement this prize court convention an attempt was made by ten maritime nations in 1908-1909 at the International Naval Conference at London to formulate the laws which the court should apply. The Declaration of London of 1909 embodied the labors of this Conference.

Not merely in these broad national matters has the formulation of the law progressed, but in recent years many such matters as the following have become subject of general international agreements: literary and artistic copyrights, 1902; sanitary measures, 1903; white slavery, 1904; potent drugs, 1906.

While rights, persons, and property, and jurisdiction on land and sea earlier had received attention, in more recent years the use of the air has been the subject of international regulation as in the conventions of 1906 and 1912. To the last of these conventions the representatives of about forty non-American political unities affixed their signatures, many of the larger states allowing here, as in some

other conventions, participation in the formulation of the law to the divisions of which the state entity was composed. The legislation thus rested upon a broader base than in many conventions of earlier years.

The progress in the application of the law for nations has been exceedingly rapid. Cases which have defied the best efforts of diplomacy for generations have been settled by due process of law in a few weeks. Cases which might have resulted in long and disastrous international contention have been resolved in the light of law. Where recourse to legal settlement of disputes was in earlier times the last resort, it has become the first, and not merely the parties to the controversy may begin the action, but third parties may of right suggest or even try to bring the parties to submit the case to the decision of the court.

A glance at conventions since 1899 will show how rapid is the formulation of the law for nations. These international laws, in addition to many private matters, cover the pacific settlement of international disputes, limitation of the employment of force in the collection of contract debts, laws for war on land, rights and duties of neutral powers and persons in war on land, status of enemy merchant ships at the outbreak of hostilities, the transformation of merchant ships into warships, the laying of automatic contact submarine mines, bombardment by naval forces in time of war, care of sick and wounded in time of war, rights and duties of hospital ships, exercise of right of capture in maritime war, prohibition of discharge of projectiles, from balloons, rights and duties, of neutral powers in time of war, the establishment of an international prize court, and the law for its guidance.

The progress of the development of a law for nations within the years since 1898, when the first proposition of the Czar was put forward, has been greater than the progress in the two hundred and fifty years preceding from the epochmaking treaty of Westphalia in 1648 to the year 1898.

At the end of the nineteenth century, conventional international law covered but little of the possible field of international contention; now but a small part of the field is not covered by formal written agreement, having after ratification the force of law not merely in

the domestic courts but in the court for the nations which will adjudicate the developing volume of international law, the court which is to be the crowning institution of the judicial systems of the world.

HARVARD UNIVERSITY,
April, 1916.

IV.

INTERNATIONAL ADMINISTRATION.

By PHILIP MARSHALL BROWN, A.M.

James Lorimer, that vigorous and most stimulating Scotch publicist, treating of the question of world organization, remarked more than thirty years ago that:

"The great impediment (in the way of the growth of international jurisprudence) . . . is the hopelessness caused by the *débris* of impossible schemes which cumber our path, and from these it must be our first effort to clear it."

Among the "impossible schemes" must probably be included Lorimer's own earnest attempt to solve this great problem which he characterized as The Ultimate Problem of International Jurisprudence.

Starting with the assumption that international order is to be secured in very much the same way as national order, he says:

"Savages are incapable of municipal organization beyond its most rudimentary stages; and yet it is by means of municipal organizations that men cease to be savages."

Following out the logic of his uncomplimentary analogy between nations and savages Lorimer reaches the conclusion that an international legislature, judiciary, and executive are required to secure that order and freedom among nations which he holds to be the aim of international law. Candor compels him to admit that

"progress in the direction of the ideal by means of mutual aid, regulated by positive law, though possible within the state *may* be impossible beyond it; the ultimate problem of international jurisprudence, while demonstrably

inevitable, may be demonstrably insoluble. The science of jurisprudence, when prosecuted in the direction of the law of nations, may end in a *reductio ad absurdum*."

Nevertheless, Lorimer has the courage to believe in an international administration of law comparable to the enforcement of municipal law.

Immanuel Kant, presenting another "impossible scheme" in his memorable essay on "Perpetual Peace," also asserts that:

"Nations must renounce, as individuals have renounced, the anarchical freedom of savages, and submit themselves to coercive laws; thus forming a community of nations (*civitas gentium*) which may ultimately extend so as to include all the peoples of the earth."

Kant is careful, however, to define his community of nations as meaning "a federation of peoples, but not necessarily an international state." He furthermore concedes that:

"This juristic state must arise from some sort of compact. This compact however must not be based on compulsory laws like that lying at the basis of a state; it must rather be that of a permanent free association, like the above mentioned federation of different states."

It would seem that Kant, in his instinctive aversion to a universal state possessing coercive powers, revealed a better understanding of the facts of international existence than Lorimer. The trouble with many such attempts to deal with international problems would seem clearly to be that confusion of thought must always arise whenever we try to reason by analogy between nations and individuals. This is evident in considering questions of honor, morality, and particularly so in treating of the international functions of the state.

In considering the problem of international administration, we ought clearly to recognize at the outset that nations do not meet together and intermingle in a community as do individuals. They do not merge their interests as savages renouncing anarchical freedom. They do not agree on common conceptions either of legal or moral rights and obligations; choose their own magistrates; accept the rule of the majority; and for mutual advantage submit to the benign rule of a common sovereign.

Individuals have every reason to come intimately together in the daily pursuit of a vital community of interests. Through their

political organization they may secure ready and effective checks on the abuse of power by legislature, judges, and executive. As live, integral parts of a municipal organization, they can regulate, alter, abolish, and create anew the national state within which they have chosen to merge their interests.

It is obvious that hardly any of this reasoning applies to international relations. The most that nations, jealous of their integrity, and conscious of their exalted missions, ask of each other is freedom to achieve their own worthy ends. That freedom is to be found in separate existence, not in community existence: in a mutual recognition of each other's interests, not in submission to a common sovereign. They cannot possibly accept the idea of a *supranational* law imposing, as does municipal law, trying restrictions, complicated obligations, or punitive ordinances. The truth of this has been exceedingly well expressed by Reinsch, in urging the necessity of coöperative action between nations, when he says:

"Any attempt to urge states into action without showing a specific need, on the mere plea of the interest of internationalism, would be, in so far, to jeopardize the normal development and ultimate success of the great movement which is one of the most notable phenomena of the era in which we are living. Nor should we expect states readily to give up that power of self-determination, of freely selecting their means, methods, and activities, which constitutes the essence of political sovereignty; however essential, in their own interest, a participation in common action may be, they still remain the principal guardians of human rights and interests, and ought therefore to retain to themselves the necessary freedom of action which such a trust requires."

The desire to convert international law into *supranational* law arises probably from the Austinian concept of the need of a superior sanction to law, a concept which has obscured the profound fact that the law of nations is of a distinctly different character from municipal law.

It may be truly affirmed that the *lex gentium* is of a more elevated nature. Applying as it does *inter gentes*, it does not appeal to the policeman; it appeals to reason itself, to the sense of equity, to a higher moral consciousness. It is based solidly on the Golden Rule interpreted in an imperative, utilitarian, and ethical sense, as enlightened self-interest. It is simply the recognition of mutual

interests, of common legal rights and obligations. And the basic sanction of the law of nations consists in the consciousness of what Gareis has concisely stated as "anticipated advantages of reciprocity as well as fear of retaliation."

It would seem clear therefore that what is needed is not a sovereign international organization to create, interpret, and enforce law. The need is rather of a complete, just, understanding between nations as to what constitutes their mutual interests.

International congresses and conferences as adjuncts to diplomacy are greatly to be favored in order to accomplish this great end. The functions of such conferences are of two kinds: one, political—and this the most fundamental—to determine the respective rights of nationalities in all that is essential to their free development; and the other, legislative, in order to formulate the law which shall safeguard these rights.

The establishment of an international tribunal as the supreme court of appeal when doubts arise concerning the interpretation of these laws is of course a logical necessity. It is by no means clear, however, that such a tribunal should possess coercive power, any more than in the case of the Supreme Court of the United States in controversies between states.

It may safely be asserted as a general principle that any compulsion of a nation that does not appeal to enlightened self-interest may prove a grave menace; and where enlightened self-interest exists there is no need of compulsion. At any rate, in a normal state of international order established on a mutual recognition of definitely formulated interests, if a recalcitrant nation should need coercion or chastisement, such an unwelcome task might better be performed through some such limited agency as an alliance of nations, whether openly avowed or in the disguised form of the proposed League to Enforce Peace. Power of such threatening proportions could never readily be entrusted by nations to the free action of a genuine international executive.

If the preceding reasoning be accepted as sound; if we concede that international law has no pretence to be *supranational* law; that it invokes no sovereign sanction, but appeals to the enlightened self-interest of states; then an international executive becomes unneces-

sary and even abhorrent. It would have a thankless task, and prove a constant cause of friction, a means of unjust coercion, a menace to national sensibilities and convictions.

The question naturally arises: how then is international law to be efficiently administered? The answer, however, seems obvious; it is to be administered by national agencies. The courts of most nations are generally sympathetic to the law of nations. It is of pointed interest to note that even now, in the midst of this fearful war, the Supreme Court of the German Empire should have seen fit to protect the patent rights of a French national actually fighting in the trenches in the defence of France!

When a court applies international law as a part of municipal law there can hardly be any doubt as to the intrinsic value of that law. The difficulty is not in the nature of the law of nations, or in its enforcement. It lies in the failure of nations to formulate that law with precision, or to provide an adequate body of law covering the wide range of subjects which so often give rise to international litigation.

This is particularly evident in that branch of international law—which is truly an integral part—well characterized as Conflict of Laws. The grounds for these conflicts should be removed. The rights of aliens in their sojournings and wanderings as citizens of the world should be defined by mutual agreement. The rights of foreign creditors should be clearly determined. So likewise in regard to what may be termed international torts, where aliens are wronged by acts of the state.

This great task remains in large measure to be performed through diplomatic agreements, conferences, and, if you will, through international legislation. The problem of the administration of this law may safely be left to national courts under the safeguard, in some instances, of an appeal to an international court.

There is no sound reason for believing that nations actually prefer recourse to war, or even to reprisals, in order to settle differences of a clearly justiciable nature. The present war has demonstrated all too eloquently the horrors, the awful cost, and the folly of litigation by force of arms. If the just political aspirations and national rights of states are satisfactorily gratified and determined,

the serious grounds for international litigation by force will be effectively removed. This can be done neither by the imperious will of a conqueror nor of an international sovereign executive. It can only be accomplished through mutual concessions, by the free will and consent of nations.

It may be thought that in eliminating the possibility of an international administration through the agency of a supreme executive, we have virtually excluded the possibility of any international administration whatever. But this is far from being the case. On the contrary, a survey of the already existing agencies for international administration proves most suggestive and encouraging.

For example, the European Danube Commission has been of very great value in time of peace in the regulation of the international commerce of the states bordering on the river, as well as of other states represented on the Commission.

The administration of the Suez Canal in time of peace has been of an international character, though as long as England controls Egypt, it would be obviously a fiction to affirm that this waterway was truly internationalized.

Tangiers may properly be denoted as an international city, administered as it is by representatives of various Powers. Its situation, however, is quite abnormal, constituting a species of *modus vivendi* in the light of the conflicting ambitions of France and Spain, the Powers most vitally concerned.

A most interesting problem awaiting solution at the outbreak of the great war in 1914 was the disposition of the icy island of Spitzbergen, where the presence of coal deposits allured foreigners of various nationalities, and required the establishment of some form of municipal administration. It is understood that some such anomaly was agreed upon in principle, though the precedent of the *codominium* of Samoa by England, Germany, and the United States certainly does not augur well for the success of another *codominium* in Spitzbergen.

We are perhaps bound in this connection to speculate somewhat on the possibility of the internationalization of Constantinople and the two neighboring straits. It may be conceded that an international administration by officials of some such nationality as the

Swiss might prove feasible of organization and successful of operation. From the political point of view, however, such an arrangement could hardly satisfy in the long run the ambitions of Russia to hold in her own hands the best natural gateway to the Empire. The uncertainty that an international administration would be able, though willing, to effectively guarantee the security and the facilities demanded by so great an Empire, would doubtless constrain Russia to vigorously oppose any such arrangement. However that may be, if it be granted that Constantinople and its approaches should be internationalized, such an arrangement would be necessarily of an abnormal, exceptional character.

Other abnormal forms of international administration are to be found in the foreign Sanitary Board, and the Dette Publique of Constantinople. Imposed on the Turks to guard against dangerous epidemics, and to protect the financial interests of European investors, these two institutions, respectively, have been an affront to Ottoman national pride, and cannot claim a permanent existence. The Dette Publique, incidentally, raises the interesting question whether there should be an international bankruptcy law which would permit of placing an entire nation in the hands of receivers for the benefit of all foreign creditors, instead of the hands of the loan sharks of one nation which for political reasons may have encouraged such loans. The Sanitary Board, likewise, suggests the question whether nations should not be authorized to intervene in the affairs of any nation which may be criminally negligent in matters involving the health of neighboring peoples.

Other special instances of abnormal administration are to be found in the mixed courts of Egypt for the trial of cases affecting foreigners, and in the foreign settlements of Shanghai, Canton, and Tientsin. It is certainly of interest to note that in countries where extraterritorial privileges still exist, foreigners have found effective ways, even while their respective nations are at war, to administer their common municipal settlements, and adjudicate their legal differences. Such arrangements, however—it must be repeated—can only be regarded as temporary and exceptional in character.

Of much more vital interest and significance from the point of view of international administration are those numerous and highly

important organizations known as Public International Unions which have to do with such matters as Communication, Economic Interests, Sanitation, Police Powers, Scientific, and other purposes.

These Unions may be characterized, perhaps, as non-political, and non-lucrative, as opposed to alliances or commercial undertakings. A mere enumeration of certain of these agencies is most suggestive. The Telegraphic Union, The Universal Postal Union, The International Union of Railway Freight Transportation, The Union for the Protection of Industrial Property, Works of Literature and Art, The International Red Cross, all of which have their home in Switzerland, have been accomplishing most beneficial results in their special fields. There are also the Metric Union in Paris, the Agricultural Institute in Rome, the International Maritime Office at Zanzibar for the suppression of the slave trade, the Permanent Office of the Sugar Convention, the International Office of Customs Tariffs, and the Interparliamentary Union at Brussels. Of a distinct character and importance is the Bureau of Arbitration at The Hague.

When one considers the wide range of subjects of so great importance to the peoples of the different nations, the imagination is stirred with the possibilities of such agencies for purposes of international administration. In just such normal, reasonable ways are the peoples of the earth best able to advance their common interests and facilitate that mutual understanding which must lie at the very base of international law. In a similar way the unlimited array of scientific, literary, religious, industrial, economic and other societies organized between nations will also contribute incalculably to the breaking down of prejudices and the "perfection of the relations between states" which, according to Lorimer, is the true purpose of international law. Diplomacy and law itself are spared considerable strain and friction by the creation of all these agencies.

The most interesting and pregnant suggestion has been put forth to the effect that a central international bureau might well be established in some such Olympic precinct as Switzerland to serve as the home of all the various public international unions, a kind of supreme "clearing house" for these and many of the other societies and organizations having a non-political, non-lucrative purpose.

Such a suggestion would seem to offer the most fruitful possibilities from every point of view as a practical means of helping on the cause of international solidarity.

An international "clearing house" which has in it the elements of great promise is the Pan-American Union in Washington. Here center the interests of twenty-one American republics. If Canada could find the way to come in, this Union would comprise virtually the whole of the Western Hemisphere, a world in itself, set apart from the troubled worlds of Europe, Asia, and Africa.

It is true that the Pan-American Union as yet possesses little power of an administrative nature. Nevertheless it exists as the tangible utterance of an ideal that may ultimately be realized. There do not seem to be any insuperable obstacles in the way of conferring increased powers on the Union to at least discuss questions of mutual interest to the nations concerned, or to recommend legislation or action which their relations may demand. It is quite conceivable that the Union might even be given legislative power to enact *ad referendum*, regulations and laws on specified topics such as intercommunication, trade, industry, and other questions of a like character. Here might gradually be centered the routine administration of many matters, very much as is done now through the various international bureaus established in Switzerland.

It is possible of course that such an organization through the natural accretion of administrative powers might take on something of the character of an international executive. Whatever might be its ultimate evolution, by serving as a general "clearing house," a central common forum for discussion, suggestion, or even legislation, the Pan-American Union would certainly prove of immense service in achieving some degree of international organization in at least this portion of a distracted world.

By way of summary, I have endeavored within the necessarily restricted limits of this paper to establish in rough and cursory outline the following points.

I. There is no true analogy between international and municipal problems. Though nations must need have recourse to war at times, they are not savages. The ends sought by individuals within a com-

munity are very different from the ends sought by nations within the community of nations.

II. International law is quite distinct in character from municipal law. It is truly *international*, and not *supranational*. It does not appeal for its recognition and enforcement to a sovereign authority. It appeals to the sanction of enlightened self-interest, to "anticipated advantages of reciprocity as well as fear of retaliation." Its enforcement must necessarily lie with national agencies though allowing for appeals in certain instances to some kind of authoritative international tribunal.

III. The great need is, not of a sovereign enforcement of the law of nations, but of a much more comprehensive and definite formulation of that law. A clear understanding of the mutual interests of states which it is the object of international law to protect is urgently required.

IV. Diplomacy and international conferences can accomplish in the main the great task of determining the rights and obligations of states, and of providing the law which should apply in controversies and litigations involving these rights and obligations.

V. Nations cannot jeopardize the freedom necessary for the achievement of their separate purposes and ideals by submitting to a common sovereign possessing coercive powers. An international executive thus becomes undesirable and repugnant, a menace to the legitimate aims and sensibilities of nations.

VI. If an international executive is undesirable, there exist, however, other agencies of great importance for purposes of international administration. The Universal Postal Union with its headquarters in Switzerland is an excellent example. By utilizing and perfecting these agencies, by providing a central international "clearing house" for the many non-political, non-lucrative interests of nations—the Pan-American Union, for example—international solidarity may be most effectively attained. In like manner the encouragement of international societies and congresses covering the entire field of human interests will be of immeasurable aid to the great cause of internationalism.

In conclusion, therefore, we would do well to consider whether in our anxiety to accomplish something definite for the cause of

world peace, it would be wise to attempt the creation of new international agencies. Would it not be prudent to follow Lorimer's injunction against "impossible schemes" and to avoid his example by adding no more "*debris*" in the pathway of international jurisprudence?

We cannot presume to foretell or anticipate the destinies of nations. A world state may yet evolve. We are not concerned however with remote events of a problematical, speculative nature. Our immediate duty would not appear to impose the creation of a perfect scheme of world organization. Does it not rather consist in the utilization and perfection of the agencies already at hand?

PRINCETON UNIVERSITY,
April, 1916.

V.

WORLD ORGANIZATION.

By DAVID JAYNE HILL, A.M., LL.D.

That there is a legal bond of relationship between the sovereign states composing the society of nations, has been amply shown by the distinguished speakers who have already presented their views. That this is in some sense a fact, no competent authority would deny; but in order to render it a secure basis for an effectual organization of the civilized nations of the world, it is necessary that there should be among them practical unanimity in accepting and maintaining a common understanding of the nature of this legal bond, and of the consequences that should follow from it.

THE CONCEPTION OF CHRISTENDOM.

Back of such a common understanding there must be, as a condition of its existence, some uniformity of conviction regarding the nature of the state, the source and extent of its authority, and the normal purposes and relations of separate political communities.

The first common ground of this kind was furnished by Chris-

tianity. Before its existence there were, indeed, certain generally accepted juristic principles, derived from the experience of right and wrong in the conduct of neighboring peoples; and an important contribution to the clearer apprehension of them was made by the Stoic philosophy, which was itself a fertile source of elementary legal conceptions. But it was the sense of a wider community, inspired by the possession of a common religious faith, involving ideas of duty, fidelity and honor, that eventually made possible a nearer approach than had ever before been made to the idea of an actual society of nations—a "Christendom," in which all races of men were, or might become, participants.

THE SOCIETY OF STATES AS DEFINED BY SUAREZ.

Looking, as Christian princes did, to a common divine source of their authority, this feeling of community had in a certain degree long existed before its natural grounds were distinctly formulated. This was first done in the sixteenth century, in a passage of remarkable clearness and depth of insight, by the Portuguese theologian, Franciscus Suarez, who wrote:

"The human race, however divided into various peoples and kingdoms, has always not only its unity as a species but also a certain moral and quasi-political unity, pointed out by the natural precepts of mutual love and pity, which extends to all, even to foreigners of any nation. Wherefore, although every perfect state, whether a republic or a kingdom, is in itself a perfect community composed of its own members, still each such state, viewed in relation to the human race, is in some measure a member of that universal unity. For those communities are never singly so self-sufficing but that they stand in need of some mutual aid, society, and communion, sometimes for the improvement of their condition and their greater convenience, but sometimes also for their moral necessity and need, as appears by experience. For that reason, they are in need of some law by which they may be directed and rightly ordered in that kind of communion and society. And, although this is to a great extent supplied by natural reason, yet it is not so supplied sufficiently and immediately for all purposes; and, therefore, it has been possible for particular laws to be introduced by the practice of those nations. For just as custom introduced law in a state or province, so it was possible for laws to be introduced in the whole human race by the habitual conduct of nations."

THE DISSOLUTION OF CHRISTENDOM.

It was, as Professor Moore has pointed out, among the Christian states that international law had its beginning; and for a long period they alone were regarded as constituting the society of states and entitled to the consideration which that law demanded. But long before the admission of non-Christian nations into that community, Christendom had completely lost its original unity; fraternity between the nations had almost vanished; schism in religion and the rivalry of dynasties had destroyed all but the ceremonial relations between states; and, although philosophic jurists, like Pufendorf and Wolf, propounded theories that rendered plausible the establishment of a world-state, the political conditions of Europe rendered them illusory.

PROJECTS FOR A WORLD-STATE.

It is especially interesting at this time to recall the fact, that most of the great projects for a thoroughgoing legal organization of the world have had their origin in periods of time when human reason and conscience have been roused to protest by the infamies that accompany great wars. Thus it was that, in the midst of the Thirty Years' War, Emeric Crucé proposed that Venice be chosen as the permanent seat of a corps of ambassadors who by their votes should settle all international differences. It was during the "Robber Wars" of Louis XIV. that William Penn, whom Montesquieu has called "the modern Lycurgus," propounded his plans for universal peace. It was at the conclusion of the struggle for the Spanish Succession that Fénelon presented to the Congress of Utrecht his famous dissertation, in which he said:

"Neighboring states are not only under obligation to treat one another according to the rules of justice and good faith; they ought in addition, for their own safety, as well as for the common interest, to form a kind of general society and republic."

It was upon the same occasion, that the Abbé de Saint-Pierre elaborated his extension of Sully's alleged "Great Design," in which—anticipating the present program of the League to Enforce Peace—he proposed not only the submission of differences to judi-

cial decision, but the total abolition of the separate use of force, and the agreement that, in case of a refusal to observe treaties or to obey the rules and judgments imposed, the other members of the alliance should compel a refractory sovereign to comply by arming unitedly against him, and charging to his account the expense of this forcible constraint. And it was during Napoleon Bonaparte's conquest of Italy, that Immanuel Kant wrote his famous essay on "Eternal Peace."

THE EXTENSION OF CONSTITUTIONALISM.

It is quite natural, therefore, that we should at this particular time experience a new interest in the problem of world organization; for it is evident, not only that all the devices hitherto proposed for securing international justice through legal procedure have thus far failed of accomplishing their purpose, but that the rescue of civilization from complete destruction depends upon some new relation to be established between force and law.

It is possible for almost any intelligent man familiar with modern constitutions to construct upon paper a plan of international organization that most other intelligent men would probably agree was worthy of universal adoption, and which some intelligent men would even affirm ought to be forcibly imposed upon all mankind by a union of constitutional states.

Some of us have hoped that the development of constitutional government throughout the world, if it had not already reached that point, would soon advance so far as to render it possible for states founded upon constitutional principles voluntarily to extend the application of them, so that they might become operative between states as well as within their separate jurisdictions; for this is all that would be required to establish a constitution of civilization that would not efface or suppress the idea of nationality, but merely recognize all responsible states, great and small, as juridical persons, bound by their own structural principles to admit their limitations, their responsibilities, and their amenability, as local organs of justice, to that greater organism of which they would form a part.

THE EXCLUSION OF IMPERIALISM.

By such a procedure there might be established that relation between law and its enforcement that is necessary for the solution of this problem; and it is not to be doubted that it is in this direction that we may seek for a solution.

It must not be overlooked, however, that, if we are to promote world organization through constitutionalism, we cannot begin auspiciously by abandoning its principles; and, by means of a forcible imposition of what we happen to consider to be law and justice, really substitute for the anarchy we deplore the imperialism we should thereby embrace.

An empire founded upon a declaration of the rights of man would, indeed, be preferable to a condition of anarchy and violence; but we have no assurance that such an empire can long exist. What we know historically of imperial governments does not encourage such an expectation. They either develop into despotisms, as the Roman Empire did, or radically change their character and become democracies. We have an example of the latter process in the transformation now taking place in the British Empire. For the first time the British colonies are persistently referred to as "autonomous"; and this word has been used in this sense by a conservative member of the government, Mr. Bonar Law, speaking for the cabinet upon an official occasion; when he made the interesting statement, that what had been impossible before the war will be easy after it, and that the relation of the colonies to the mother-country would never again be what it was before. In fact, it is a confederation of autonomous states, rather than an empire in the proper sense, that is coming into existence in what has been known as the British Empire.

It is in this modification of the conception of sovereignty—which must yet endure even greater modifications—that we find a ground of hope for a permanent and pacific organization of mankind. Unless we start out with the postulate, that the State is founded upon the inherent rights of its citizens; and, therefore, reaches its limits of authority where their collective rights of safety and possession end, we shall have no constructive principle upon which to base a

better organization of the world. The right of superior aggressive force once admitted, no matter how noble and elevated its aims may be, imperialism has triumphed; and, if imperialism is to triumph, it will create its own rules of action in defiance of international law.

THE ANTAGONISM OF THE CONSTITUTIONAL AND THE IMPERIAL IDEALS.

As the basis of any practicable scheme of world organization, it is necessary to lay down the postulate, that every free community of men may form a government for the protection of their inherent rights. But this fundamental political right, which we call by the ambiguous name "sovereignty," is by no means an unlimited right. It is necessarily limited by the similar right of other coëxistent communities; and, from the constitutional point of view, it is further limited by the fact that there are inherent personal rights, which no government may justly take away.

I am aware that a contrary view is held, which maintains the unlimited right of majorities to determine what the law may be; but, upon this principle, it is evident that the greater Powers, simply by the preponderant weight of numbers, might wholly extinguish the smaller nations. That is the theory of imperialism, which claims an unlimited right of national expansion, restrained only by the measure of power to carry it into execution. Its motto is "Might makes right."

Constitutionalism, on the contrary, proceeds upon the principle that local liberty should be secured by general law. It is opposed to forcible aggression, and resorts to force only in its own defense. It accords to a neighbor the same rights that are claimed by itself. It proposes a gradual substitution of law for force in the regulation of the world.

THE OUTLAWRY OF VIOLENCE.

Being itself a product of a long process of social evolution, and dependent for its very existence upon those growths of mind and character that qualify men for self-government, constitutionalism cannot expect an immediate or an easy triumph. It must patiently abide its time, until the nations shall have acquired the wisdom to

organize justice by voluntarily accepting the limitations which it imposes.

There is, however, one means of promoting this result without a resort to violence. When nations manifest fitness for admission into the Society of Sovereign States, they are admitted to its privileges. When they violate its laws, and by their conduct show their unfitness for participation in it, why should they not be denied the privilege of intercourse with civilized nations?

There is, it is true, no central authority possessing the power to render a sovereign state an outlaw; but any government, in standing for the maintenance of international law, or for the vindication of its own rights under it, may, if it is willing to pay the cost, sever its diplomatic and its trade relations with a persistent law-breaker.

But the cost would often be considerable; and, judged from the point of view of expediency, it requires either a serious offense or a certain amount of courage to take such a step. But, without courage, so long as savagery, brigandage, and imperial ambitions disturb the peace and order of the world, there can be no international progress. Whatever rights, or prestige, or influence any nation possesses to-day, it enjoys because someone has defended them.

THE DUTY OF NATIONAL DEFENSE.

And so, after a general survey of international relations, we are forced to the conclusion, that, between submission to injustice and the ability to defend the rights of a nation, there is no alternative. But there is still another aspect of the subject. The maintenance of the reign of law in the world against aggression and violence must be regarded as a duty which every civilized nation owes to every other, as well as to itself. International law is our law. We have helped to make it; we hold ourselves under obligation to observe it; and we cannot, without moral delinquency, refuse to defend it.

So long as armed force is necessary to maintain human rights, it is incumbent upon us to furnish our contingent for their defense. It may be that a right course will be resented, and that the severance of diplomatic and commercial relations with a powerful nation might provoke an attack in response. Very well; then it becomes our duty, not only in defense of the reign of law, but in our own defense, to be prepared to resist it.

For this purpose it is only a confession of feebleness to depend upon alliances. There is no strength in a rope of sand, and no positive result can come of the mere addition of nullities. If conflict becomes necessary, someone must bear the brunt of it. The future peace and order of the world depend upon the attitude of the great nations. To be a great nation, and at the same time to refuse to assume a great nation's responsibilities, is a recreant evasion of duty.

Applying this doctrine to the United States of America, our influence for peace and justice will be in proportion to our strength. If we are weak, our only safety lies in silence; but in a great moment silence is dishonorable. If we would speak with effect, we must be strong. We do not require a great standing army, but we should be able, in case of need, promptly to place in the field an army proportional to the nation's territorial extent; for it is that which we may be called upon to defend. But above all, we should be strong upon the sea; for it is there that the destinies of the world are to be determined.

WASHINGTON,
April, 1916.

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WASHINGTON,
April, 1916.

AGE CYCLES AND OTHER PERIODICITIES IN ORGANISMS.

By C. M. CHILD, Ph.D.

(Read April 15, 1916.)

According to the group of biological theories of which the Weismannian theory is the best example, the process of aging is irreversible and progresses always in one direction. Young individuals arise from the germ plasm, that fountain of perpetual youth, and once started on the path of development there is no turning back for them but they go on inevitably toward the one end—death. These theories neglect, however, to tell us why a part of the living protoplasm of a species should differentiate, grow old and die and another part remain perpetually young, and why, once started on the downward path, there is no possibility of return for the developing organism.

Within recent years the suggestion has been made more than once that development may be a reversible process and the fact has been established beyond doubt, that at least many cells, even in the higher animals, may undergo more or less dedifferentiation as well as differentiation. Since aging or senescence is very evidently closely associated somehow with the processes of development and differentiation we are then brought face to face with the question; can cells or organisms grow young as well as grow old? If rejuvenescence as well as senescence is a characteristic feature of life then we must expect to find that young cells or organisms arise, not from a perpetually young germ plasm, but from old cells or organisms through changes in the opposite direction from those which constitute senescence. Life from this point of view is then a cycle consisting of alternating periods of senescence and rejuvenescence. If such age cycles exist, we should expect to find them in their simplest terms in the simple organisms, and in my own experimental

attack on this problem I have been primarily concerned with these simple organisms.

It has long been known that in the higher animals and man the most characteristic physiological feature of the process of senescence is a progressive decrease in the rate of metabolism, or of certain fundamental metabolic reactions from birth and undoubtedly from still earlier stages onward. This is accompanied, as Minot and others have shown, by a decrease in the rate and final cessation of growth.

In my own experiments on the lower animals I have found that a similar decrease in metabolic rate and rate of growth occurs during the life history. A very simple method has made it possible to use the metabolic condition to a very large degree as a criterion of physiological age. This method depends on the fact that the susceptibility to many, if not all, agents which kill by decreasing metabolism in one way or another, varies with the general metabolic rate. In concentrations of such agents which kill in the course of a few hours the individual with the higher metabolic rate is the more susceptible and dies sooner than the individual with lower rate. This method has been checked and controlled by various others in many ways and can be used very widely for comparing the metabolic condition of different individuals among the lower organisms.

I have found that the general metabolic rate in the simple animals, particularly in certain of the planarian worms which have been the chief experimental material, decreases from a very early stage of development on through life, as growth and development proceed. A progressive decrease in rate of growth also indicates that these animals undergo senescence.

These planarians undergo a process of fission in nature in which the posterior body region separates off and becomes a new individual, but we do not need to wait for the occurrence of such fission, for we can induce the development of new individuals by cutting the animals into pieces. Each piece develops a head at its anterior end, a tail at its posterior end, and undergoes more or less dedifferentiation and internal reorganization and usually develops into a new whole with the characteristic structure of the species, but

of smaller size than the individual from which the piece was taken, the size of the new individual depending on the size of the piece. In undergoing this reconstitution the piece uses up a part of its own body substance as a source of energy and of the new cell material formed.

A test of the metabolic condition of the new individual thus formed shows that it is physiologically younger than the animal from which the piece was taken, and the smaller the fraction of the original body from which it developed, the younger it is. By feeding it can be made to grow, to go through the life history and to become old again, and may then again be cut into pieces which once more become young individuals, and this process can be carried on for a long time, probably indefinitely. I have carried an experiment of this sort through twenty generations. Evidently the process of reconstitution of these pieces into new animals in some way brings about a greater or less degree of rejuvenescence.

Another experiment affords a clue as to the manner in which this rejuvenescence occurs. If the full-grown planarians which are 25–30 mm. in length are deprived of food, they do not die of starvation in a few days, but gradually become smaller, and can be reduced to a length of a millimeter or less before death occurs. Tests of metabolic condition show that during this reduction the metabolic rate is increasing, the animals are growing younger. Morphologically also they show indications of rejuvenescence. By feeding we can stop this process of rejuvenescence at any time and make the animals begin to grow old again, and we can repeat this process again and again.

In another species of planarian in which the length of the life cycle under ordinary conditions in nature is about two months, I have been able to keep the same individual worms alive and in essentially the same physiological condition for a much longer period than the usual length of life, simply by regulating quantity and quality of food, *i. e.*, the animals were fed just enough of the food, found by experience to be most suitable, to prevent reduction in size and not enough to permit growth. With this procedure they remained in practically the same physiological condition, of

the same physiological age during nearly four years, while other members of the same original stock, fed in the usual way, passed through some twenty generations.

These experiments afford some insight into the nature of the process of senescence and rejuvenescence. We see that when the animal is adding to its protoplasmic substratum by growth and transforming it by processes of differentiation it is growing old, but when it is using up previously formed protoplasmic material, as it does in reconstitution and starvation, it is growing young. In the simple animals where the structural substratum of the body built up under one sort of conditions is readily broken down under other conditions in the absence of nutrition, or in reconstitution, rejuvenescence occurs readily and may carry the animal back almost to embryonic stages, but the evolution of the higher forms is very evidently associated with a physiological stabilization of the structural substratum of the body and we find that in man and the mammals bodily rejuvenescence is apparently limited. A large part of the structural substratum is either not available for nutritive purposes or cannot be broken down rapidly enough to supply the demands, and death occurs before any great degree of rejuvenescence has taken place in the body as a whole. But that some slight degree of bodily rejuvenescence may occur even in man cannot be doubted.

It is impossible to consider here all the various lines of evidence, but it may be said that the facts at present available indicate that senescence consists in a decrease in metabolic rate determined by the changes in, and the progressive accumulation of, the relatively stable components of the protoplasmic substratum during growth, development and differentiation. Rejuvenescence, on the other hand, is an increase in metabolic rate determined by the breakdown of previously accumulated structural substances in dedifferentiation, starvation and reproduction and the development of new protoplasmic substance in place of that eliminated. We may say, in short, that the organism grows old when the primitive embryonic protoplasmic substratum is modified or added to by changes in the colloids and accumulation of relatively stable components by growth

and differentiation, so that the protoplasm becomes less active chemically, and that it grows young when the protoplasm previously thus modified loses these modifications to a greater or less extent and approaches or attains the primitive undifferentiated or embryonic condition and becomes more active chemically. The youngest protoplasm is protoplasm reduced to its lowest terms as a colloid substratum of chemical reaction and aging occurs as this protoplasm is modified by changes in the colloids and accumulation of relatively inactive substance.

In the lower animals the processes of asexual reproduction are essentially similar to the reconstitution of pieces experimentally isolated and all such processes are accompanied by some degree of rejuvenescence. Even in the unicellular animals, I have found that every cell division with its accompanying processes of reorganization, giving rise to a new individual is accompanied by some increase in metabolic rate, *i. e.*, some degree of rejuvenescence. Under certain conditions senescence and rejuvenescence may balance each other and asexual reproduction may continue indefinitely, while under other conditions the degree of rejuvenescence may not be sufficient to balance senescence in each generation, and in such cases a progressive race senescence occurs.

Turning now to sexual or gametic reproduction, we must inquire how it is related to the age cycle. The facts are these: the sex cells develop only at a very advanced stage of the senescence period of the individual, and in many of the lower animals sexual maturity can be experimentally prevented by keeping the animals physiologically young through asexual reproduction or reconstitution or even periodic starvation. If the sex cells are perpetually young, undifferentiated cells it is not easy to account for the relation between sexual maturity and advanced physiological age.

As regards their morphological structure, the sex cells are among the most highly differentiated and specialized cells in the organism. The period of their development from the mother germ cells is a period of growth and differentiation like that of the other parts of the organism during development. Physiologically also this period is a period of decreasing metabolic rate, of senescence

in all cases thus far examined. In short, both morphological and physiological evidence force us to the conclusion that the mature sex cells or gametes are highly differentiated, physiologically old cells.

It has been shown by Loeb, Warburg and others, that an increase in the rate of oxidation follows fertilization and Warburg has shown further that an acceleration of the oxidation-rate continues through the cleavage stages and at least to the swimming larval stage in the sea urchin. I have found that in all forms examined thus far, including echinoderms, annelids, fishes and amphibia, the increase in susceptibility during early development indicates that the rate of metabolic reaction increases up to a certain stage of development and then begins to decrease. All the facts at hand then indicate that the early period of embryonic development is a period of physiological rejuvenescence. Morphologically also it is a period of dedifferentiation. The highly specialized structure of the egg is lost and the cells gradually become undifferentiated or embryonic in appearance.

In fact the evidence indicates very clearly that the sexual reproductive cells or gametes represent the final stages in a period of differentiation and senescence, that their union initiates a process of rejuvenescence which continues through the early stages of embryonic development and is followed again, as the differentiation and accumulation of structural substance overbalance dedifferentiation and reduction, by a period of senescence which may be practically continuous throughout the life of the individual as in the higher animals and man, or which may be interrupted or balanced by periods of rejuvenescence connected with asexual reproduction and other processes, as in many lower forms. The stage of most extreme youth is not then at the beginning of embryonic development but at some later stage, varying in different animals and in different tissues of the same body.

If these conclusions are correct there is no germ plasm in the sense of a perpetually young protoplasm handed on from generation to generation, but the organism undergoes growth, differentiation and senescence as a whole and in both asexual and sexual reproduction rejuvenescence occurs. In the higher animals and man

sexual reproduction is the only process and the sex cells the only cells in which any very great degree of rejuvenescence occurs in nature, but in the lower forms all cells of the body may undergo rejuvenescence as well as senescence in asexual reproduction, starvation, and various other processes. Even in the mammals and man, however, evidence is accumulating that at least many of the tissue cells may undergo a considerable degree of dedifferentiation and rejuvenescence under proper conditions and with the further development of experimental technique we may expect further evidence along this line.

If this point of view is correct, life, so far as age is concerned, is a periodic cycle in which senescence alternates with rejuvenescence. The periods of growth and differentiation, in short of development, are the periods of senescence, the periods of dedifferentiation and reduction, the periods of rejuvenescence. It can be shown further that in at least many cases the process of senescence by decreasing the effectiveness of the physiological integrating factors in the individual leads automatically and necessarily to the physiological isolation of parts and so to reproduction of one sort or another and rejuvenescence. The sequence of the two periods follows necessarily from the constitution of protoplasm. The period of senescence is the period of accumulation and decreasing dynamic activity, and in the highly integrated individual it may end in the death of some or most parts. In any case, however, the period of senescence leads in one way or another to the physiological isolation of cells or multicellular parts, as I have shown elsewhere,¹ and these, if they are capable of continued existence after such isolation, undergo dedifferentiation just as the piece experimentally isolated from the planarian body undergoes dedifferentiation, because the conditions which previously maintained differentiation are no longer present and the supply of nutrition is cut off. If the isolated part lives, it lives at the expense of its own substance and the portions of it which required the special conditions resulting from the physiological association with other parts for their formation and maintenance are the first to break down and serve as a

¹ Child, "Individuality in Organisms," Chicago, 1915.

source of energy. In this way the isolated part undergoes a process of dedifferentiation and in so doing becomes physiologically younger and approaches or attains the generalized or undifferentiated condition of that particular protoplasm. If sufficient energy is available in the form of nutrition, either from its own substance or from its environment, this period of dedifferentiation is followed by a new period of differentiation and senescence. In other words, from being a differentiated, specialized part it becomes an undifferentiated or generalized whole by the loss of its specialized features and then undergoes a new course of specialization as its constitution determines.

In the evolutionary adjustment between the period of rejuvenescence and environmental conditions natural selection has unquestionably played an important part, for it is evident that no species can persist from generation to generation in which a source of nutrition is not available in time to save the parts concerned in reproduction from death by starvation. If this were not the case the period of dedifferentiation and rejuvenescence would end in death, as in the case of the starving planarian. Rejuvenescence may follow senescence automatically, but for a new period of senescence following the rejuvenescence, nutrition from without is sooner or later necessary.

We must now inquire whether this age cycle is unique in organic life or whether there are other periodicities which in any way resemble it. I believe there are many other periodicities of essentially similar character. Fatigue, for example, as distinguished from exhaustion, results from the accumulation of substances which retard metabolism and recovery, from the removal of these substances. The chief difference between this periodicity and the age cycle is that the substances which produce fatigue are products of catabolism, essentially waste products and that they are soluble and readily removed, while in age they are essential constituents of the differentiating protoplasmic substratum.

Again, the period of so-called loading of the gland cell is a period of decreasing metabolism and accumulation of substance with marked change of structures in the cell and resembles the

period of senescence except that it may take place in a few hours. The loaded gland cell, like the egg, usually requires stimulation before it is able to initiate the process of discharge, but, once begun, this process undergoes acceleration, the metabolic rate rises, the cell loses its peculiar structure and becomes less specialized in appearance. This is comparable to a period of rejuvenescence, and in the presence of nutritive material this period is again followed by a period of loading and decreasing metabolic rate.

In the green parts of a plant in the presence of light and carbon dioxide loading of the cells with starch and a progressive decrease in activity occurs, while in darkness the starch may be transformed to sugar and carried to other parts, and the cells regain their former condition.

Again in seasonal and other periodicities similar alternations appear, a period of accumulation and decreasing dynamic activity is followed by a period of quiescence in which recovery gradually occurs or after which activity may rapidly increase when external conditions such as temperature permit. Periods of encystment following growth and accumulatory periods in the lower organisms, and periods of hibernation or estivation following periods of active nutritive intake are to a greater or less degree essentially periods of rejuvenescence.

In many of these cases the beginning of the period corresponding to rejuvenescence is determined by environmental rather than internal factors but this is incidental. The progressive period instead of proceeding to its natural termination is interrupted, and a regressive period initiated by external conditions. The organism in such cases merely responds to the rhythms in its environment, but such responses are minor periodicities which show certain resemblances to the periodicity of the age cycle. The course of life is then a complex periodic curve made up of many periodicities of various lengths, the normal age cycle being the longest for the individual.

But in conclusion, we may at least raise the question whether there are not periodicities of this sort extending beyond the life of the individual. Is there not evidence in favor of the view that evo-

lution is a secular senescence of protoplasm, interrupted here and there by periods of rejuvenescence? Such periods of evolutionary rejuvenescence if they have occurred, have probably, like some of the minor periods in the life of an individual, been determined by environmental factors, for the natural, internally determined period of secular protoplasmic senescence has not yet reached its termination. In any case the general similarity between evolutionary and individual differentiation suggests that similar factors are at work in both cases, and since the period of individual differentiation is in general a period of senescence, the suggestion that something of similar character is occurring in evolution is not wholly unwarranted.

UNIVERSITY OF CHICAGO,
April, 1916.

TYPES OF NEUROMUSCULAR MECHANISM IN SEA-ANEMONES.

By G. H. PARKER, S.D.

(Read April 15, 1916.)

Sea-anemones possess at least four systems of organs by which they react to environmental changes: the glandular system, especially the mucous glands, the ciliary system, the nematocyst system, and the muscular system. Of these the first three are strictly local in their responses in that they become active only in the exact regions where they are stimulated. Moreover they remain normally responsive in animals that have been so completely anesthetized with magnesium sulphate or chloretone as to exhibit no nervous activity. Hence there is good reason to assume, notwithstanding the opinion held by some of the older workers, that none of these three systems are under nervous influence. The fourth system, the muscular, is well known to be controlled by the nervous system of these animals. In the common New England sea-anemone, *Metridium marginatum*, the neuromuscular mechanism includes at least thirteen muscles or groups of muscles. Two of these are ectodermic, (1) the longitudinal muscle of the tentacles and (2) the radial muscle of the oral disc; the remaining eleven are entodermic and are as follows: (3) the circular muscle of the tentacles, (4) the circular muscle of the oral disc, (5) the circular muscle of the oesophagus, (6) the sphincter, (7) the circular muscle of the column, (8) the circular muscle of the pedal disc, and the five mesenteric muscles, namely, (9) the basilar muscles, (10) the longitudinal mesenteric muscles, (11) the transverse mesenteric muscles, (12) the parietal muscles, and (13) the longitudinal muscles of the acontia or netting filaments.

The nervous mechanism by which these muscles have long been supposed to be brought into action is a network of neurofibrils and the like which permeates the deeper regions of the ectoderm and the

entoderm and the two parts thus established are believed by many investigators to be continuous in the oesophageal region where ectoderm and entoderm are confluent. According to O. and R. Hertwig (1879-1880), Wolff (1904), and others this nervous network is more extensively developed in the oral disc than elsewhere and constitutes there a primitive central nervous organ. Grošelj (1909), however, believes that this centralization is in the oesophagus. Many other workers (Nagel, 1892; Loeb, 1895; Parker, 1896; Havet, 1901; Bethe, 1903; Jordan, 1908, 1912) maintain that this network is not sufficiently centralized anywhere in the actinian's body to justify the statement that the nervous system of the sea-anemone is other than a diffuse one.

Vigorous stimulation of almost any part of the surface of a sea-anemone is commonly and quickly followed by the complete contraction of the whole animal; and the response is so protracted that actinian muscle has come to be regarded as specially adapted to tonic contraction rather than to the rapidly changing phases of contraction and relaxation so characteristic of the muscles of the higher animals. This view has gained such strength that von Uexküll (1909) and Jordan (1909, 1908, 1912) have come to look on these muscles as almost exclusively tonus muscles and Jordan (1908) especially has gone so far as to deny to sea-anemones the possibility of muscular reflexes such as are so usual among the more differentiated animals. An adequate examination of the muscular activities of sea-anemones will show, I believe, that these animals have a much more complex muscular mechanism than has been previously suspected and that at least three and possibly four types of muscular activity can be distinguished in them.

The simplest of these types is that seen in the longitudinal muscle of the acontium. This muscle can be brought into action by the direct application of an appropriate mechanical or chemical stimulus. Its contraction changes the acontium from a long straight filament into a loosely twisted, spiral one. This response is strictly local in relation to the stimulus and does not spread appreciably from the region stimulated to other parts. It is as well pronounced in acontia that have been in an anesthetizing solution (magnesium sulphate or chloretone) long enough to abolish all nervous activity in other parts

of a sea-anemone as it is in normal acontia. I therefore conclude that the acontial muscle is one that is normally stimulated directly and that it is without nervous connections. In this sense it represents primitive muscle unassociated with nervous tissue as has already been identified in sponges (Parker, 1910).

A second type of muscle is that seen in the circular muscle of the column of *Metridium*. When a portion of the column of this animal is fully anesthetized with magnesium sulphate, a mechanical stimulus will not elicit from it the usual contraction of the animal as a whole, but a ring of contraction will extend more or less completely around the column. When the column is not anesthetized and the sea-anemone is vigorously fed, this muscle exhibits peristaltic movements which apparently depend upon nervous activity. The circular muscle of the column, therefore, seems to be a muscle open to direct stimulation and also under the control of nerves. In this respect it resembles the sphincter pupillæ of the vertebrate eye which responds not only to nerve impulses but also directly to light.

A third type of muscular mechanism in sea-anemones is seen in the longitudinal muscles of the mesenteries. These contract when almost any part of the surface of a *Metridium* is stimulated, but they fail to respond when the animal is deeply anesthetized. Hence I conclude that they are primarily controlled by nerves. Under ordinary stimulation their action is profound and lasting and is one of the most important elements in the general contraction of the animal as a whole. It is their activity that in large part has given grounds to the idea that the actinian muscle is specialized almost exclusively on the side of its tonicity.

Finally a fourth type of muscle mechanism is that seen in the transverse muscles of the mesenteries, particularly of the complete mesenteries. When food juice is discharged on the tentacles or lips of an expanded *Metridium*, the transverse mesenteric muscles contract and thus open the œsophagus preparatory to what under normal circumstances would be the swallowing of the food. On withdrawing the stimulus these muscles quickly relax and the œsophagus closes. This reaction is so definite and precise in its

relation to the stimulus and so invariable in its occurrence that it must be regarded as a true reflex and as an example of such an operation it certainly compares very favorably with what is often seen in many of the higher animals.

The muscular reactions of the sea-anemones are then by no means all of a kind, but range from direct muscle responses of a most primitive character to true reflexes. The more complex operations of these animals such as food-taking, creeping, and so forth, are not to be regarded as the result of the action of a relatively uniform neuromuscular mechanism, but depend upon some combination of the various types of muscular or neuromuscular activity possible to these animals. These operations are often extremely complex and call for a high degree of coördination and yet this coördination is almost entirely of local origin, for an isolated tentacle will react to food almost exactly as an attached one does and the pedal disc, even after the oral disc has been cut away, will creep in a fashion indistinguishable from that of a whole animal. There is therefore good grounds to agree with those who maintain that the nervous system of the sea-anemone is essentially diffuse lacking obvious centralization.

HARVARD UNIVERSITY,
April, 1916.

INHERITANCE THROUGH SPORES.

By JOHN M. COULTER, A.M., PH.D.

(Read April 14, 1916.)

The modern history of botany is a series of segregations of subjects. Each new segregate has attracted a certain number of recruits from the older subjects. There have always been two categories of botanists: those who move on promptly to the newer phases of their subject, and the old guard that never moves on. The latest segregate of the series is plant genetics, which is making so large an appeal to botanists that if the epidemic continues all botanists are in danger of becoming geneticists. What I wish to present has a bearing upon the work of this important modern field of botanical activity. In this presentation, however, I shall not introduce the details of material. These details are too numerous for the time allotted, and too technical for any audience excepting one of professional botanists.

Plant geneticists have begun, just as did plant morphologists, by using the most complex material. So long as plant morphologists focused their attention upon seed plants, they were accumulating data that could only be interpreted empirically. When they included a study of the lower forms, the simpler groups became keys to the more complex ones, and interpretation became scientific. In plant genetics we are still mainly in the stage of complex material. Sexual reproduction is selected as the method of reproduction to be investigated, and the particular sexual structures selected are so peculiarly involved with other structures that it is impossible to analyze the factors involved in the results. Not only are the sexual structures beyond the reach of observation and of experimental control, but there is an alternation of two forms of reproduction, inheritance being carried through one generation to express itself in the next.

Furthermore, the origin of embryos produced in seeds is not assured. While we may assume that, for the most part, they are the result of fertilization, which in its gross aspects can be controlled, the increasing number of cases of parthenogenesis, vegetative apogamy, and sporophytic budding introduces a serious element of uncertainty. The program between pollination and fertilization, and between fertilization and the escape of the embryo from the seed, is a very long one, and not a single stage of it is under observation, much less under control. In other words, we are working empirically upon our problem as yet.

If sexual reproduction must be studied, it would seem desirable, therefore, to use material selected from the more primitive sexual forms, material in which the sexual structures are not so involved with other structures, in which the whole performance of fertilization and embryo development is in sight and capable of control. The difference between a sex act and an embryo development under cover, and in the open, when experimental control is the end in view, is too obvious to need further explanation. Furthermore, in these simpler sexual forms the origin of sex is observable, so far as it is represented by the sexual cells, and the general conditions of origin are known, conditions which are sadly in need of analysis in experimental work. It must be evident that a knowledge of the factors involved in the origin of sex may throw some light on the function of sex in general. But the origin of sex involves a still more fundamental problem.

Sexual cells are phylogenetically related to spores, that is, spores are historically intermediates between vegetative protoplasts and sexual cells. This suggests that the origin of spores and inheritance through them deserve attention as a preliminary to the origin of sexual cells and inheritance through them. In other words, there are certain things that all forms of reproduction have in common, and these should be kept distinct from the things which are peculiar to sexual inheritance.

More primitive than reproduction by spores is reproduction by ordinary protoplasts, shown notably by one-celled plants in which cell division results in reproduction and in which the succession of

cell divisions is rapid. The fact that such plants can be induced to form spores contrary to their normal habit, indicates that the conditions of spore formation can be determined. These conditions are described as yet in terms so vague that they mean little more than environment, and this may be external or internal, depending upon whether one speaks from the standpoint of the plant or of the protoplast. Experimental work has shown that a spore may be defined as a protoplast, usually separated from its old wall, always separated from organic connection with other protoplasts, and by virtue of this latter fact, capable of producing a new individual. If this is a spore, what is a sexual cell which may be derived from the same protoplast? Neither of them is a protoplast of special cell lineage, as has been proved by inducing spore formation and gamete formation in any cell lineage.

The plant geneticist may not be interested in the conditions that result in gamete formation, and even less interested in the conditions that result in spore formation, but these are fundamental to the problem of reproduction, and therefore fundamental to the problem of inheritance. A practical plant-breeder may be interested only in the fact that he can obtain a new individual from a seed, the pedigree of whose embryo in the nature of things cannot be demonstrated, but only inferred; but a scientific plant-breeder, whom we now call a geneticist, must be interested in the conditions that determine inheritance, and these include the conditions that determine reproduction in general.

No more favorable material for determining the fundamental facts of inheritance can be found among plants than spores of the simpler forms. They are accessible, and therefore capable of control; a succession of spore-produced individuals represents a line whose purity cannot be questioned; the so-called "modification of the germ plasm" can be accomplished with a precision that is impossible in an ovary and ovule-enclosed egg, to say nothing of the sperm. In short, freed from all entanglements of sex, the possibilities of variation in pure lines can be determined, and the possibilities of the inheritance of such variations. Such work will establish the facts common to all inheritance, and will enable us to recognize the contribution of sex to inheritance.

To indicate that this is not a visionary programme, I wish to say that such experimental work has been begun, and that the initial results indicate that the stage of promise is merging into the stage of performance. It is demanding not merely the technique of plant-breeding, but it involves also the technique of cytology to discover the structural changes, and the technique of physics and physiological chemistry, to determine the conditions and substances that are factors in the various processes. Perhaps of largest significance is the fact that just as the doctrine of evolution broke up a static taxonomy, so this experimental work with inheritance is breaking up a static morphology, encrusted with rigid definitions, and is making this great field dynamic.

THE POPES AND THE CRUSADES.

By DANA C. MUNRO, L.H.D.

(Read April 13, 1916.)

The First Crusade was the work of Pope Urban II., whose wonderful speech at the Council of Clermont led thousands to take the cross. From that time the Popes always felt that the crusades were peculiarly their task and under their inspiration, even if some of the expeditions, like the one against Constantinople, escaped from their direction. For they believed that the crusades were God's work and that they were His agents. According to Fulk of Chartres, Urban at Clermont used the following words:

"I speak to those who are present, I shall proclaim it to the absent, but it is Christ who commands. Moreover, if those who set out thither lose their lives on the journey, by land or sea, or in fighting against the heathen, their sins shall be remitted in that hour; this I grant through the power of God vested in me."

The Pope set the time of departure, ordered who should go and who should not go, offered privileges to the participants, and threatened with excommunication all who should not fulfill their vow. For two hundred years and more the Popes were always proclaiming that the crusades were on imperative duty and everyone recognized their preëminent concern in the holy wars.

Why did the Popes enter upon this undertaking? What did they hope to gain for the Church and for Christendom from these crusades? Many have attempted to answer these questions and their answers have been very contradictory, too often reflecting merely the prejudice of the writer. Thomas Fuller in his *History of the Holy War* said:

"Though the pretences were pious and plausible, yet no doubt the thoughts of his holiness began where other men's ended, and he had a privy project beyond the public design: First, to reduce the Grecians into subjection to himself, with their three patriarchs of Jerusalem, Antioch, and Constantinople; and to make the Eastern Church a chapel of ease to the mother church of Rome."

Without quoting farther from Fuller we may note that many scholars have agreed with him that the main purpose of the Popes' action was the desire to bring the Greek Church under the Roman curia. The most notable exponent of this idea in recent years is M. Köhler, the editor of the *Revue de l'Orient latin* and of the Armenian Documents in the *Recueil des Historiens des Croisades*, and one of the best informed scholars in this subject.

Others have thought that Urban was moved by the appeal for aid from the Emperor at Constantinople, and with the broad view of a statesman realized the necessity of protecting Europe most effectively by carrying the war into the enemy's country. It is possible that he foresaw the gain in authority that would accrue to the papacy from the leadership in a universal movement which would arouse religious enthusiasm and be conducted under the guidance of the Church. It is also possible that he was influenced mainly by the spirit of the age, with its kindred virtues of asceticism and valor. As most of his letters concerning the crusade have been destroyed, there is not enough material to make it possible to dissect and weigh his motives. It is easier to understand and explain why the succeeding Popes should have continued to interest themselves in a movement which they believed to be God's work and which was apparently bringing such important results to the Church.

In the first place the preaching of the crusades aroused great religious enthusiasm and led many sinners to reform, at least temporarily. Peter the Hermit preached right living as well as the Crusade; and, in particular we are told by one of those who had seen him that "he led the prostitutes back to their husbands and added to their dowries from his own resources." Some of the preachers had many qualities of the modern evangelist: a biting wit, a ready tongue, a keen sense of humor, a magnetic personality; some were accused of evil-living and greed. Fulk of Neuilly, who claimed that he had given out 200,000 crosses with his own hands, raised money to build a house for magdalens and for a church, as well as for the cause of the crusades. He bandied jests equally readily with Richard the Lion-Hearted and with the mob. When the crowd pressed too closely upon him he would lay about him vigorously with his staff and those who were hit felt honored by

the blows. On one occasion when some in his audience tried to secure as relics bits of his garments, he seized upon the most presumptuous and proclaimed that his own clothes were not sacred objects, but that he would and did sanctify the garments of the man he held, whose clothes were at once torn from his body, in bits to be preserved as relics. Such preachers naturally appealed to the common people, who seldom heard any sermons, and had a great influence in kindling religious zeal. The preaching of the crusades frequently led many to enter monasteries to expiate their sins, instead of taking the Cross. Cæsar of Heisterbach tells of the marvelous effect of Bernard of Clairvaux's sermons and states that Bernard sent all who were fit into monasteries; to the others he gave the Cross. After the fall of Jerusalem such a wave of piety spread over western Europe that wars were abandoned for a time and the cardinals took a vow to go afoot until the Holy City was rescued from the infidel. In the next century a most striking outburst of religious enthusiasm led to the Children's Crusade, which was to be a missionary movement, not a military campaign. Thus, undoubtedly, through the preaching of the crusades there was a great amount of religious fervor, some real piety and reformation in manners, and a greater interest in the Holy Land and all connected with it. This would redound to the credit of the head of the Church and increase his influence and power.

The Popes offered privileges, both spiritual and temporal, to all who took the Cross. Because of the intense enthusiasm for the crusades and also because of the weakness of most of the monarchs in Western Europe during the first half of the twelfth century, the Church, and especially the Pope, were allowed through these privileges to encroach upon the sphere of the temporal authorities. All crusaders were given the protection of the ecclesiastical courts; thus when a vassal took the cross he might escape to a considerable extent from the jurisdiction of his feudal lord. Moreover, his family and property were taken under the protection of the Church and in this way many cases were taken from the feudal courts. In his privilege for the Second Crusade Eugene III. gave vassals who took the Cross, the right, under certain circumstances, to mortgage their fiefs

without the consent of their suzerains; this was a direct encroachment on property rights, but amid the intense enthusiasm for a movement in which both the German emperor and the French king participated this usurpation passed without much comment. It is significant, however, that this privilege was not renewed in later grants. The Popes also gave permission for non-payment of interest on debts owed by crusaders and directed that the monarchs should take steps to enforce this. Philip Augustus actually followed the mandate, by an ordinance arranging the extent to which this non-payment of interest should be allowed. This encroachment upon property rights provoked less opposition because the creditors were frequently Jews. As each crusader was under the protection of the Church the Popes interfered in case of capture of individual crusaders by their enemies and also to prevent warfare which would hinder men from fulfilling their vows. They used the censures of the Church freely for this purpose and, on the whole, with general approval. They even interfered with the amusements of the nobility, repeatedly forbidding tournaments and threatening to excommunicate all participants. Other instances might be cited to show the manner in which the Popes added to their temporal power and control over those who were not members of the clergy, so that after a century of crusading activity the Pope's power had been enormously enhanced. Of course, the increase in their temporal authority was not wholly due to the crusades; other agencies were at work; but the religious wars preached by the Popes had a very important share in the growth of temporal power which had reached so great an extension by the time of Innocent III.

In the thirteenth century the influence of the crusading movement in adding to the Pope's power can be illustrated in many ways. Frederic II., in a burst of enthusiasm caused by his unexpected attainment of the imperial crown, took the Cross. From that time until he started on his expedition, twelve years later, he was continually hampered by his vow and had to make many concessions to the Pope, in order to obtain permission to delay its fulfillment. When an energetic pontiff, Gregory IX., was elected, Frederic was obliged to start on his expedition, although he had not completed his

diplomatic preparations. When he put back on the plea of illness he was excommunicated and his crown placed in jeopardy. He probably regretted frequently and very bitterly his youthful enthusiasm. The Pope preached a crusade against his Sicilian kingdom; and this illustrates another means by which the power of the popes was enhanced. They repeatedly preached crusades against their temporal foes and offered to the participants in these wars the same privileges, spiritual and temporal, which were given to those who went on expeditions against the Moslems. These holy wars were sometimes directed against monarchs and other rulers, sometimes against cities, at other times against heretics like the Albigenses, or against the heathen in the north and northeast of Europe. These armies played an important part in the history of the thirteenth century.

This century also saw the temporary union of almost all Christian lands under the authority of the Pope and this was directly due to the crusades. The capture of Constantinople led to the establishment of a Latin patriarchate there. Bishops of heretical churches in Syria acknowledged the supremacy of the Latin Church. The ruler of Armenia sought to have the title of king bestowed upon him by the Pope and promised in return to bring the Armenian Church under the Pope. For a time there seemed a possibility that there might be one all-inclusive Catholic Church, under the authority of the Pope.

The crusades also brought to the Church and to the Popes an enormous increase in wealth. Crusaders gave freely to the Church before starting for the East; they also mortgaged or sold their property to ecclesiastical foundations under conditions very advantageous to the latter. The Orders of the Temple and Hospital received great endowments and became very wealthy. Men who had taken the Cross and were unable to go, purchased exemption from their vow. Taxes for the crusades were frequently collected and handled by the Church. It is not possible to give any estimate of the total amount which the Church received through the crusades, but it was enormous. Consequently the Popes became much more powerful, especially through their control over the appointment of the officials who profited by this wealth.

While the Popes and the Church gained so much in so many different ways, their disappointments were severe and their losses heavy. There could be no disguising the fact that the crusades, on the whole, had been a failure. When the monarchs returned home ignominiously from the Second Crusade even Bernard of Clairvaux felt sick at heart over the failure of the movement which he had preached. The Crusade of Richard the Lion-Hearted and Philip Augustus had not rescued Jerusalem; the Fourth Crusade had been shamelessly diverted against a Christian Empire; the Fifth had secured a diplomatic triumph which the Pope did all in his power to thwart and belittle; the minor expeditions had achieved little or nothing; the heroic St. Louis had been obliged to ransom himself from captivity. These failures did not injure the papal power to any marked degree because the Popes and their legates had been responsible for the conduct of the military operations only to a very limited extent. For the First Crusade Urban II. had appointed a papal legate, Ademar of Puy, who proved of great assistance to the expedition; he died before the capture of Jerusalem and his loss was keenly felt by the crusaders. Although other legates were sent with the various expeditions, no one played a prominent part, except Cardinal Pelagius, whose lack of tact, to put it mildly, was principally responsible for the failure of the Crusade against Damietta. The leaders of the various crusades to the Orient were not designated by the Popes. With the exceptions of Urban II. and Innocent III., the Popes did not take an active part in laying the plans for Crusades against the Moslems; the expedition for which Urban made the plans was successful; Innocent's orders were not obeyed. The leaders in the Church, like St. Bernard, were able to throw the blame for failure upon the ignorance and sins of the crusaders.

Jerusalem was conquered and held for some scores of years but the Holy City did not become the head of a Church state as the Pope probably hoped that it would. When, before its capture in 1099, the leaders gathered to discuss the election of a ruler, the Church party in the army protested, saying that no earthly monarch ought to wear a crown of gold where our Saviour had worn a

crown of thorns. For the moment the nobles yielded; after the capture of the city they elected Godfrey, Defender of the Holy Sepulcher. This title probably marked a concession to the point of view held by the clerical party. When Dagobert was elected Patriarch of Jerusalem and demanded that Godfrey should give up the Holy City, the latter temporized, promising that he would hand over Jerusalem to the Patriarch when he had secured other conquests. But after his death his brother Baldwin was crowned king, and Jerusalem gradually became an hereditary monarchy, in which the Patriarch was clearly subordinate to the King, and the latter was wholly independent of the Pope. The Christian conquests in Syria, instead of being the home of garrisons ever ready to propagate the faith by the sword, soon became commercial centers whose inhabitants were intent mainly on living in peace and carrying on trade with the infidels. They viewed askance the bands of crusaders from the West who might interfere with their commerce by provoking hostilities. Even members of the military Orders, whose main purpose was supposed to be the defence of the Holy Land, formed friendships with the Moslems, whom they entertained in their castles and allowed to pray to Allah in their chapels. The direction of the great Crusades escaped from the Popes, and in spite of Innocent's commands and repeated excommunications the French and Venetians persisted in going to Zara and Constantinople and in sacking those Christian cities. Frederic II., excommunicated for not going on a crusade, went and was excommunicated again for going while excommunicate. Despite the efforts of the Pope and of the leading churchmen in the Holy Land he made peace with the Mohammedans and secured Jerusalem by diplomacy. The crusaders who settled in the Holy Land soon ceased to be as devout and narrow as their brethren in the West. They intermarried with the natives, both heretics and Moslems, adopted the customs of their wives, and some of their superstitions. Even the Templars were generally believed to be contaminated by the Mohammedan beliefs. The monastic chroniclers, especially those from the West, are very outspoken about the evil lives led by the Christians of all ranks, even the patriarchs, in the Kingdom of Jerusalem. From the East these

conditions spread to the West, to the great detriment of the Church. The merchants carried back not merely Oriental wares, but also Oriental heresies, which spread rapidly in the West along the commercial highways. Soon crusades had to be preached against the heresies which were mainly due to the crusades. All of these factors detracted from the power of the Popes.

It was easier for the heresies to spread because of a growing distrust of the Church, due to many causes, *e. g.*, all teaching in France, Germany and England had been done by the clerics and the crusaders found that many things which they had been taught were untrue. One chronicler of the First Crusade naïvely expressed his surprise at the bravery of the Turks who he had been taught to believe were cowards. Possibly this idea was due to Urban's speech at Clermont, for William of Malmesbury reports that the Pope said: the Turks are

"feeble men, who, not having courage to engage in close encounter, love a flying mode of warfare. For the Turk never ventures upon close fight; but, when driven from his station, bends his bow at a distance and trusts the wind with his meditated wound; and as he has poisoned arrows, venom, and not valor, inflicts death on the man he strikes. Whatever he effects, then, I attribute to fortune, not to courage, because he wars by flight, and by poison. It is apparent, too, that every race, born in that region, being scorched with the intense heat of the sun, abounds more in reflection, than in blood; and, therefore, they avoid coming to close quarters, because they are aware how little blood they possess."

Many another crusader learned that the information which he had received had been misinformation, and began to doubt. The political crusades brought discredit upon the Church and the Popes who ordered them. Many men realized that the Popes were using their power for worldly ends. In the thirteenth century it was ever more difficult to induce men to take the Cross. In 1233 the Pope offered an indulgence of 20 days to all who would listen to a sermon on the crusades; in 1249 the indulgence was increased to 40 days, and in 1265 to 100 days, in the hope that some might be led to take the Cross.

Many of the preachers were charged with misappropriation of the funds which they raised for the crusades. Walter von der Vogelweide voices this feeling in his verses:

"Little, methinks, of all this silver in God's cause is spent:
To part with a great treasure priests are ill-content."

As Walter was a partisan of the Hohenstaufens and opposed to the papacy he might be considered prejudiced. But the same idea was common; *e. g.*, Matthew Paris, the historiographer of the monastery of St. Albans writes:

"By divers wiles the Roman curia strove to take their property from the simple people of God, seeking nothing but their gold and silver."

Thomas Fuller, later, put it bluntly, the pope "got a bag of money by it." All reformers in the Church felt that this wealth had brought corruption in its train and while few realized the part that the crusades had played in bringing in this wealth, many denounced the corruption of the papal curia and its greed for gold.

Church unity was attained for only a short time. The Greek Empire, for whose aid the First Crusade had been preached, had been brought under the Latin Church, but had been so weakened by the attacks of the crusaders that it could not much longer be "the bulwark of Europe" against Islam. The fall of the Latin Empire of Constantinople led to the return of the Greek patriarch. Heresy and opposition to the Church spread in the West. There was a marked decline in religious fervor; interest in the next world dwindled as the zest in living the present life increased, because it seemed better worth living. There was a great growth in the use of indulgences and it would be especially interesting to trace out their connection with the privileges of the crusaders. It is not feasible here, however, to follow the whole course of events. The facts which have been given are sufficient to show how completely the hopes of the Popes had been frustrated. If we weigh all the evidence we see the manifold ways in which the crusades affected the power of the Popes and we may well conclude that some roots of the reformation are to be found in them and the Popes' connection with them.

PRINCETON UNIVERSITY,
April, 1916.

A RARE OLD SLAVONIC RELIGIOUS MANUAL.

(PLATE V.)

By J. DYNELEY PRINCE, Ph.D.

(Read April 13, 1916.)

In the library of Mr. J. Pierpont Morgan in New York City is a very rare old Slavonic Roman Catholic prayer-book, printed in Glagolitic characters in the so-called Croatian variant of the Church Slavonic language. The work bears the Latin title at the end of the text: *Alphabeticum et Preces Illyricae, impr. Ven. per Andream de Torresanis de Asula*, 1527, followed by the Slavonic title: *štampani v* Býnetcich po Andrei Torezani iz Ašuly*, "printed in Venice by Andreas de Torresanis de Asula," which words are followed by the date, 1527, indicated in Glagolitic characters. On the front fly-leaf are written the words: *é libris Evelyn, Venetiis*, 1645. This undoubtedly is John Evelyn, the well-known English virtuoso, who visited Venice in 1645, and evidently purchased this book there (cf. National Biographical Dictionary, p. 79). According to Bishop Butler (Renouard, *Tom. II.*, p. 276), this work was unique in his time (1774-1839) and a collated and perfect copy. The first allusion of recent date to this edition of A. de Torresanis de Asula seems to have been made by Dobrovský in his correspondence with Kopitar, published by Ritter Vatroslav von Jagić. It is interesting to note that A. de Torresanis was also the printer of the first book in Serb proper ("The Hours") in Venice, 1493.

This Morgan edition of the Croatian prayer-book is the only one which can be placed at the present time, although there must be several copies in existence in European libraries. The book consists of seven clearly printed pages in excellent preservation and contains many woodcuts. On the front binding are two portraits; on the left, of a crowned queen, with the Italian legend: *scetri e*

* See below on the notation.

corone doppo morte F(=fanno) nulla, "scepters and crowns are of no avail after death," and on the right, of a man, apparently a king, with the Italian device: *caran(?)o (=corono) la vita mentre opero bene*, "I crown (my) life by working well." On the rear binding on the left, is a portrait of a man with the words: *colgi le rose e lassa star le spine*, "pluck the roses and leave the thorns," and on the right, of a woman with the partially erased phrase: *c- . . . misura ogni suo passo*. There is no title-page, the text beginning directly, as shown by the accompanying plate, with the Glagolitic alphabet, followed by a complete syllabary (*ba, be, bi, bo, bu, by, b:*) and the *Pater Noster* and *Ave Maria*.

The Church Slavonic language was originally the vernacular of the Macedonian Slavs at the time of SS. Cyril and Method, the two great Greek missionaries of the Eastern Orthodox faith to the wild Slavonic tribes. When these various Slavonic peoples adopted the Eastern form of Christianity with its accompanying rite, this language began to take on different aspects under the influence of the particular idioms. Thus, we find a Serbo-Croatian, a Russian and a Bulgarian reduction of the Old Slavonic, in each of which countries the older language appears partially disguised under the garb of the respective vernacular. It should be remarked that the Serbs and Croats are linguistically identical, differing only, in that the Serbs write their language in a modified form of the Cyrillic alphabet, while the Croats, who are for the most part Roman Catholics, use the Latin letters. The Old Slavonic, having been accepted at an early date as the idiom of the Scriptures and the Liturgy, naturally became the first literary language of the Serbo-Croats. Although this Church language was not identical with the Serbo-Croatian vernacular of the fourteenth and fifteenth centuries, it must have been fairly intelligible, as it became the regular literary medium in the hands of the ecclesiastical classes, from whom all literature naturally proceeded. From the thirteenth to the eighteenth centuries, all Serb books were, therefore, printed in the Old Slavonic of the Serb redaction, under which head much of the early Croatian literature also falls, although the Ragusan and Dalmatian literatures made use of the actual vernacular as their vehicle much

earlier than did the Serbs themselves. We find essentially the same conditions affecting the use of the Church Slavonic in Russia, where the older idiom appears as an archaized dialect of Russian in Old Slavonic dress. Among the Bulgarians, however, who were of Hunnic origin, their adopted Slavonic idiom differed less than Serb or Russian from the primitive Church Slavonic form of Macedonian, which is sometimes, therefore, erroneously known as "Old Bulgarian." Church Slavonic is not "Old Bulgarian," but simply stood in a very close relationship to the Slavonic dialect adopted by the Non-Slavonic Bulgars.

The Croats came very early under the influence of the Roman rite, which, however, was permitted by the Pope to be celebrated in the Old Slavonic language, which thus took on the specially Croatian form, in which the Morgan text is printed. This Croatian variant is practically identical with the Serb redaction. Its chief characteristics are the omission of the nasalized vowels of the original Macedonian and a few other concessions to the current vernacular, some of which will be noted below. It is interesting to observe that this Croatizing idiom written in Glagolitic is still in use among the Roman Catholics of Istria, Dalmatia, the Adriatic islands, and, in fact, all along the Croatian coastland. The Croatian Old Slavonic in Glagolitic has, during the course of centuries, become the medium of a very considerable literature (cf. v. Jagić, in Branko Vodnik's *Einleitung zur Kroatischen Literaturgeschichte*, Agram). In fact, there are to this day some old people who can read no other character than the Glagolitic, which went into disuse at a very early date among the Orthodox Slavs, who universally adopted the Cyrillic, which thus became the parent of the modern Russian, Serbian and Bulgarian alphabets. It is probable that the Cyrillic system was an evolution from the Greek uncial letters, while the Glagolitic, now a distinctly Roman Catholic alphabet, was developed from the Greek *minuscule* (Isaac Taylor, *Archiv für Slavische Philologie*, V., 191 ff.).

The Morgan text is especially interesting, because it presents the Croatian Church Slavonic of the early sixteenth century in a highly satisfactory manner, as may be seen from the following transliterations with commentary of the "Lord's Prayer" and "Hail Mary" shown on the accompanying plate (Plate V).

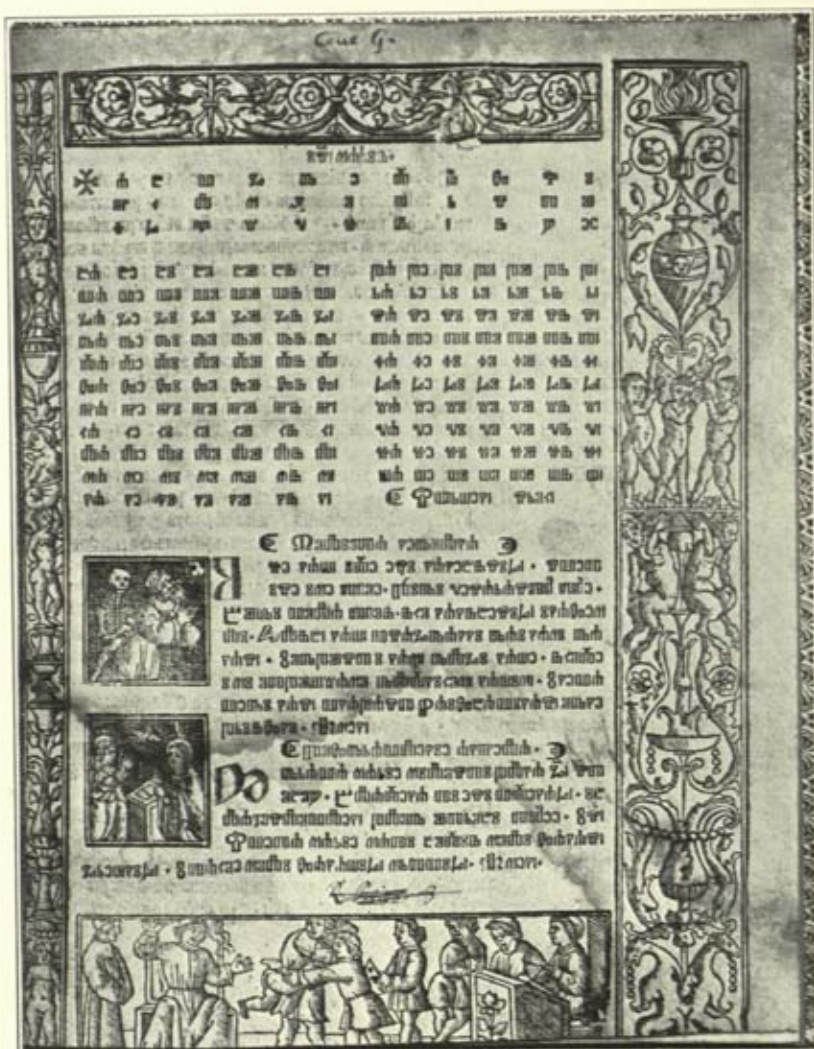
The following system of notation has been adopted. The consonants and vowels are to be pronounced as in Italian, except in the case of *â* = Roumanian *â*, *î* = heavy *ũ*, as in Turkish *kız*, "girl"; *c* = *ts*; *č* = Eng. *ch*; *ch* = Germ. guttural *ch*; *ě* = *ye*; *e* = *e* in "met"; *ja* = *ya*; *je* = *ye*; *l*, as in *dlgi*, "debts," is pronounced with the inherent vowel of the *l*, as occurs often in Czech; *r*, as in *mrtvich*., is pronounced with the inherent vowel of the *r*, similar to the vowel of the *l*; *š* = *sh*; *št* is one letter, formerly pronounced *sht*, as indeed is still the case in Bulgarian. In Russian, this combination = *shch*, all in one sound, a later modification of the primitive pronunciation. In the Glagolitic text, *ý* is an indeterminate symbol used indifferently for *ě*, *je*, *ja*, *e* and in some Glagolitic texts even for *i*; *ž* = *zh* (French *j*). The signs : and ' represent respectively the Russian hard sign, originally an indeterminate vowel, probably *ũ*, and the Russian soft sign, at first an *i*, which later developed into a mere palatalizing of the preceding consonant, as *naš'* = *nash'*. The hard sign : is not always used in the Morgan text and the soft sign ' does not appear at all.

In addition to the material treated in this paper the Morgan text contains some selections from the Psalter—the version of Ps. CX is especially interesting—the Magnificat, the symbols of the Apostles and a few prayers. I intend to publish later a complete redaction of all this material which is particularly valuable for the study of the Croatian variant of the Old Slavonic.

MOLITVA NEDILNA.

WEEKLY PRAYER.

M. oče	naš: iže	na nebýsich:		sveti-se
Z. ot'če (oče)	naš' iže	(j)esi na nebesech:		da svâtít: sâ
Cr. oče	naš koji	si na nebesima		da se sveti
Father	Our who	art in heavens	;	be sanctified
M. ime tvoe	pridí cesarstvo tvoe	budi vola		tvoý
Z. imâ tvoe	da pridet cēsar'stvie tvoe	da bâdet volě (volia) tvoě		
Cr. ime tvoje	da dodje carstvo tvoje	da bude volja		tvoja
name thy	;	let come kingdom thy	;	let be will thy
M. ýko	na nýbesich i na zemli	Chlěb: naš: vsagdanni		



FIRST PAGE OF MORGAN TEXT

Z.	ěko (iako)	na nebesě	i na zemī	(zemli)		Chlěb: naš' nad'nevnuōi
Cr.	kao	na nebu	i na zemlji			Hljeb naš' potrebnī
	as	in heavens	so also on earth			; Bread our daily
M.		dai		nam		danas
Z.	(nasuštnōi)	dai	(podavai)	nam na vsek: (vsāk:)		d'n'
Cr.		daji		nam svaki		dan
		give		us to-day (Z. for every day)		;
M.	I odpusti	nam dligi		naše ýkože		i mi
Z.	I ostavi	nam: grěchōi (grěchi)		našā iko (ěko, iako)		i sami
Cr.	I oprosti	nam grijehe		naše jer		i mi
	And forgive	to us sins		our as		also we
M.	otpuštamo	dlžnikom:		našimi		I ne vavedi
Z.	ostavlěem:	všekomou dlžnikou (dolžniku)		našemou		I ne v:vedi
Cr.	oprašamo	svakome dužniku		svojemu		I ne navedi
	forgive	debtors		our		. And not lead
M.	nas: v napast	na	izbavi	nas	od nepriězni	Amen
Z.	nas: v iskoušen'e n:(no)	izbavi	nōi (nas:)	ot nepriězni		Amen
Cr.	nas u napast	nego	izbavi	nas	od zla	Amen
	us into temptation	but	deliver	us	from evil.	Amen.

Pozdravlēnie And'ela

Greeting of the Angel

M. *Zdrava Marie milosti plna. G (ospod') s tobōju . Blažena Ti esi*
 Hail Mary of Grace full. The Lord with Thee. Blessed Thou art
v ženach. I blagoslavlēn: plod utrobi tvoee Is(ous). Sveta Marie
 among women. And blessed the fruit of womb thy, Jesus. Holy Mary,
Mati Božy' moli za nas: grešnich: . I takoe moli za našich:
 Mother of God pray for us sinners . And also pray for our
mrtvich: Amen.
 dead (ones). Amen.

COMMENTARY.

Pater Noster.

The abbreviations M., Z., and Cr. indicate respectively Morgan Text, Codex Zographensis, and the modern Croatian version. It will be observed at once in the text of the *Pater Noster* that M. is true Old Slavonic and approaches closely to the idiom of the Z. version. Note

the following peculiarities: M. *naš*: = Z. *naš'*, with soft sign, probably the original form; *nebysich*: interchanging with *nybesich*, illustrating the indeterminate character of the Glagolitic *y*; M. *sveti-se* = Cr. *se sveti* with omission of 3 p. — *t*, seen in Z. *svâtit: sâ*; M. *pridi* — *budi*, imperatives, instead of cohortative *da* in the other versions; here M. seems more archaic than Z.; *tvoy*; *y* = *ia*; *ŷko*; *ŷ* = *ě* or *ia*, as *ŷkože*; in *nybesich*, *ŷ* is clearly *ě*, as in *chlěb*; *danas* "to-day" is modern Croat from Old Slavonic *d'n' + s'*; cf. Czech *dnes*, "to-day"; note the form in M., *vsagdanni* "daily"; *otpušštamo*, with pure Croatian ending of 1 p. pl. — *amo* = Z. *ostav-l-čem*; *dlžnik* = modern Cr. *dužnik* with loss of *l*, as is characteristic in the modern idiom.

The following differences of translation should also be noted: Cr. *potrebni* does not mean "daily," but "necessary"; the Russian Slavonic form *nasuštnōi* also means "actual; needful." Observe the change in modern Cr. from the vowelless preposition *v* into *u*, in *u napast* "into temptation."

The forms in parentheses represent the variants of the Russian Church Slavonic from the text of the Codex Zographensis.

Ave Maria.

Note that *takoe*, "also," appears in modern Croatian as *takod-je(r)*. The ordinary western version of the Ave Maria ends: "pray for us sinners now and in the hour of death," whereas the M. version has "pray for us sinners and for our dead (ones)," a most unusual variant in a Catholic work!

The Russian Old Slavonic version is as follows: "O Virgin Mother of God, Hail. Blessed Mary, the Lord is with thee. Blessed art thou among women and Blessed is the fruit of thy womb, whom Thou hast borne as a Salvation for our souls." I can find no trace of either this or the Croatian version of M. in any Catholic work. It is significant, however, that in the many Orthodox hymns to the Virgin, she is regarded as the special patron of the faithful departed, which probably accounts for the M. variant laying stress on this particular aspect.

JOINTING AS A FUNDAMENTAL FACTOR IN THE DEGRADATION OF THE LITHOSPHERE.

PLATES VI-VIII.

BY FREDERICK EHRENFELD, PH.D.

(Read April 14, 1916.)

This paper is the result in part of a study of the various factors of rock weathering and erosion which I began some years ago and which has been influenced further by a study of the effects of marine erosion along the north Atlantic coast.

At a certain point I had the idea of trying to find for mechanical weathering a definite factor comparable to the part which chemical non-equilibrium plays in chemical weathering; further study convinced me, however, that there is one factor which is constantly acting in advance of all other factors of both weathering and erosion, and that this factor is jointing.

In almost all studies and in most textbooks and other geological writings on the subjects of weathering and erosion the matter is usually approached from the point of view of the contact of the atmosphere, and the results of both weathering and erosion are often spoken of as the attaining more or less perfectly of an equilibrium between the surface of the lithosphere and agents of the atmosphere. Thus both the formation of "clay" and the formation of a "peneplain" or base level are regarded as the final products of weathering and erosion; they are the conclusion of a cycle of changes which began in a condition of non-equilibrium, ran through various well-marked stages and ended at last in so-called final products which would or do remain permanent until some general earth change takes place, when a similar cycle will begin anew. If this is a fair statement of the matter, as I think it is, then these are the results of the contact of lithosphere and atmosphere to produce a surface equilibrium.

When, however, the much larger subject of the reduction of the lithosphere in general to a condition of something like equilibrium is considered, these so-called final products of "clays" on the one hand and of "peneplains" on the other are seen to be not final at all but are really the end products of a series of agents which are more or less accidental or local. The second point then upon which I wish to rest a case is that the degradation of the lithosphere including both the factors of weathering and erosion is something which is not essentially atmospheric in its control but is rather something which is a fundamental feature of the lithosphere structure itself; and that all the agents of frost, surface drainage, glacial action, chemical weathering or other surface or atmospheric agents are by their nature essentially accidentals which do influence local results but are not the controlling factors. If I may illustrate the point by an appeal to some other framed structures besides the lithosphere such as the behavior of metals under stress, we may make the comparison by considering the active life or coherency of a pair of car wheels or axles. This active life is conditioned not so much by nature of the particular train of which the wheels or axles are a part but rather by the nature of the steel and also by the fact that it is almost, if not quite, impossible to make masses of steel which will be destitute of flaws which will become joints, or to make a steel which will continue elastic. The fact that one wheel may outlive the other twice over in active service is more a question of time factor than it is of difference of the agent which produced the final break; the eventual cause of the break will in the vast majority of cases be due to some inherent factor in the wheels themselves rather than to a particular agent or a particular occasion or accident. One of the great problems of metallurgy to-day is to produce a steel without joints and it is also one of the problems of geologists when they try to conceive of the lithosphere without these same fundamental lines of weakness which we call joints; almost the only condition of the lithosphere where we can hypothecate no jointings is in a molten mass.

This tendency of earth matter to arrange itself in definite lines of weakness seems to become more striking the farther we investigate the fundamental structure and the behavior of the lithosphere

under geological conditions. Even unconsolidated sands show this same disposition under the atmosphere to arrange themselves in the repeating patterns which are so common in the case of rock masses undergoing disintegration under the influence of the atmosphere. One of the illustrations of this I wish to show is from the behavior of the loose sands which overlie the Talbot formation along the Delaware Coast (Figs. 1-2. Plate VI). These sands are disintegrating and falling in a series of parallel lines which are surprisingly like the joint control of weathering in such a place as the Grand Canyon of the Colorado and indeed in many mountain and other elevated rock structures. This parallelism shown even in these loose sands seems to appear in practically all types of rock structure and would seem to be part of the essential character of rock masses themselves, though I do not in this case, of course, mean that these sands are to be regarded as jointed; I do mean, however, that the shape of the sand under disintegration is something which is due to the nature of the sand itself and is not atmospheric in its original cause.

The literature regarding joints and jointing structures is now large and widespread. It need not be reviewed in detail here as it is general principles that I wish to discuss, not the details of the literature. However, certain general works may be cited. Earlier discussion will be found in the work of Günther;¹ also Günther;² Leopoldt and Peschel;³ Penck;⁴ Supan.⁵ All geologists are doubtless familiar with the discussions, on earth features including joints in the monumental work of Suess on "The Face of the Earth." Later literature references may be found in papers by W. M. Davis in the publications of the United States Geological Survey, and to his papers in the *Bulletin*⁶ of the Geological Society of America.

Those who are interested in the nomenclature of faults and joints may consult the report of the committee⁷ of the Geological

¹ "Lehrbuch d. Geophys.," Stuttgart, 2 vols., 1883.

² "Handbuch d. Geophysik," 2 vols., Stuttgart, 1899.

³ "Physische Erdkunde, etc.," Leipzig, 2 vols., 1879-80.

⁴ "Morph. der Erdoberfläche," Stuttgart, 2 vols., 1894.

⁵ *Grundzüge der Phys. Erdkunde*, 1911.

⁶ Vol. XXIV., pages 187-216 especially.

⁷ *Bull. Geol. Soc. Amer.*, Vol. XXIV., pp. 163-186.

Society of America; Hobbs⁸ in a long series of papers has discussed quite fully the subject of jointing in the relation to earth features and surface conditions. I. D. Scott⁹ discusses joints and fracture systems as effecting relief and control of drainage and gives also a summary of the literature on the general topic of joints. One of the surprising things about this literature in regard to joints is the almost complete agreement among textbook writers in the comparative neglect of jointing as a really important active factor in earth dynamics; the subject of jointing is usually considered as a phase of structural geology rather than as an active controlling agent in the behavior of the lithosphere. This is, I believe, a serious neglect and a condition of affairs which is totally unwarranted by the nature of the subject. One of the chief points I wish to emphasize in this discussion is the proposition that earth fracturing is one of the essential active fundamental geophysical constants akin to igneous agents in the continuity of its action and the universality of its results, that it is inherent in the nature of the lithosphere; no portion of the world as we know it to-day is free from the action of jointing and I believe it can ultimately be demonstrated and proved that this jointing of the lithosphere has been active throughout the past geological history as a general controlling factor in the great geographic and paleographic changes shown by the records of historical geology. Evolution of the lithosphere without the controlling influence of jointing seems to me an impossible hypothesis.

It may be worth while to classify into a few general groups the manner in which jointing is now seen to be a controlling factor in the changes occurring in the lithosphere; among these groups may be cited the following:

- (a) Repeating patterns of authors.
- (b) Control of river drainage.¹⁰
- (c) Coast lines.¹¹

⁸ Details may be found in "Earth Features and their Meaning," New York, 1912; "Earthquakes," New York, 1907; see especially *Bull. Geol. Society of America*, Vol. 15, pp. 483-586.

⁹ Gerlands, *Beitr. zur Geophysik*, XIII., 1914, pp. 163 ff.; *idem.*, pp. 241-260.

¹⁰ Hobbs, "River Systems of Conn.," *Journal Geology*, Vol. IX., 1901, pp. 469-485. Iddings, *ibid.*, Vol. XII., 1904, pp. 94-105.

¹¹ Hobbs, "Lineaments of the Atlantic Border Region," *Bull. Geol. Soc. Amer.*, Vol. XV., pp. 483-506.

- (d) Boundaries of geological formations.¹¹
- (e) Tectonic control of earthquake shocks.¹²
- (f) Atmospheric weathering such as in the Grand Canyon, boulder weathering, etc.
- (g) Shore lines.¹³
- (h) Valley formation due to faulting under joint control.¹⁴
- (i) Grand features of the earth as related to lines of fracture and block movements resulting therefrom.¹⁵
- (j) Plateau fracturing and disintegration.¹⁶

Other literature might also be cited but these references are deemed enough for the immediate purpose of illustration.

It is evident, then, that systems of fracture along definite lines of direction extending both over wide areas of country and in lines of great length, are to be regarded as playing a major part in lithosphere evolution, and that jointing must be regarded as one of the active agents at work in the behavior of the lithosphere.

The discussions in the literature of the science concerning the origin and nature of fjords illustrate probably as well as any one phase of the subject the attitude of writers toward the relation of joints to earth-structure. Günther¹⁷ gives a résumé of the discussions of theories regarding fjords and groups them into the following classes: The Depression Theory, the Cleavage or Fracture Theory, the Glacial Theory, the Erosion Theory. It will be noted that all but one of these theories seek to explain the origin of fjords upon some basis really exterior to the nature of the lithosphere con-

¹¹ Hobbs, "Earthquakes," New York, 1907, *passim*; includes also reference to other joint literature.

¹² Shaler and Tarr, "Geology of Cape Ann, Mass.," 9th Ann. Rep. U. S. G. S., 1887-88, pp. 529-611.

¹³ Kemp, "Preliminary Report on the Geology of Essex County, N. Y.," Report N. Y. State Geol. Survey, 1893, pp. 438 ff.

¹⁴ Hobbs, *Bull. Geol. Soc. Amer.*, Vol. XV., pp. 503-506.

¹⁵ E. Erdmann and Nathorst, Erdmann, "Descr. de la form. carb. de la Scania," 1873, Royal Swed. Geol. Institution. Nathorst, "Geol. Foren Stock," IX., pp. 74 ff. See also Suess, "The Face of the Earth," Vol. 2, especially for résumé of these papers and also discussions of the structures of the Canadian and Baltic shields. (The English translation by Sollas is the one referred to.)

¹⁶ Günther, "Lehrbuch," Vol. II., 1882, pp. 463 ff.

struction. Thus, Supan¹⁸ says that "There can be no reason to doubt that fjords are submerged valleys," and compares the Laxe Fjord of Norway to the one which would be formed by the submergence of the wedge-shaped Thalbuch of Salzburg, supposing that the sea were to overflow it. This may be perfectly true as far as it goes, but it leaves yet unexplained the reason for the similarity of the structure of the two places indicated and also fails to explain one of the characteristics of fjord coasts and that is their remarkable parallelism of structure, a parallelism which unites their structure with the parallelisms seen in other aspects of the surface of the lithosphere. The fracture or splitting theory is attributed by Günther to Peschel and Leipoldt and may be stated as follows: The destruction and breaking up of the coast was attended with its ascension; originally the cracking or splitting was not farther than the ascent of the greater layers which, in consequence of the uplift, arched over and later the fracturing extended through a shrinkage and diminution of the mass. "The uplift and destruction were simultaneous." It was proposed in brief that the destruction and breaking up of the coast was contemporary with its ascension. The erosion theory and the glacial theory have been involved in the wide discussion in the literature, as, also, may be said of the depression theory. It may be objected to each of these that it uses an agent which is more or less accidental as a primary cause and makes no allowance for the nature of the rock or material structure of the coast and also fails to explain the remarkable parallelism of fjord structures. Moreover, as has been indicated in the literature quoted, there are numerous other places to be observed where the present structure of the lithosphere would produce a fjord coast if it were to come in contact with marine erosion; the Grand Canyon area, also the canyons of the Yellowstone and indeed the parallelism of small stream valleys such as may be seen in the Appalachian folds near Harrisburg, for example, possess the necessary physical structures to produce a parallel indentation of the coast, supposing that some agent of erosion, such as glaciation, were to be involved. Glaciation then and marine erosion are to be regarded as accidents, not as the primary cause of fjord coasts. Even if we assume that

¹⁸ *Op. cit.*, page 579.

fjords are submerged valleys, that still does not explain the parallel structure which is to be observed on both sides of the north Atlantic coast; indeed, the similar character of the rock structure on the north Atlantic coast, in America and Europe both, and in the islands of the Arctic Sea, demand a general structure rather than simply a general agent.

When the discussions of principles concerning fjord structures are applied generally to a wide tract of the earth's surface, such as for example the North American continent, certain points may be shown, and I wish to suggest that that part of the North American continent included between lines drawn from the mouth of the McKenzie river through Great Bear Lake and Great Slave, Athabaska, Winnipeg, and the Great Lakes and another line drawn from Cape Cod to Nova Scotia parallel in general with the St. Lawrence river up to Newfoundland, is controlled by a series of master joints whose general angles of direction may be read from the lines of present sea-coast, lake distribution, entrance of sea channels, bays and harbors and that these are all to be conceived of as essentially attributable to a general cause which is independent of local conditions and is an essential part of the structure of the North American continent. Further, that this great extent of continental land has been in the past and is now, although it is often regarded as one of the fixed segments of the lithosphere, undergoing disintegration and degradation in a manner controlled essentially by something which is independent of atmospheric contact and may be explained on the supposition of the falling apart of a series of segments of the earth due to the development of these lines of jointing. I conceive this disintegration and development of jointing to be due to the loss of elasticity in this portion of the lithosphere. This mass of the continent has been since Archean times loaded repeatedly by the reception of sediments extending from early Paleozoic to Mesozoic times, it has been flooded from time to time by water, overrun by glacial ice, and even if not presumably subjected to elevation or subsidence it has nevertheless been subjected to a series of earth pressures and strains so that a series of master joints have become a primary part of its structure.

That under the combined attack of atmospheric weathering in

its various aspects, and also under the attack of the forces of the sea, these joints have become great lines of weakness, so that the whole outer portion of the lithosphere is here undergoing a profound and far-reaching disintegration. This sequence of events of repeated loading by sediment and erosion of the surface by ice caps has produced a wornout condition of the lithosphere structure at this point, so that even if we regard the Canadian Shield, and analogously the Baltic Shield, as one of the fixed segments of the earth, we may still observe that it is undergoing degradation just as other surfaces of the earth are undergoing degradation. The fact that it may be regarded as fixed so far as up and down motion is concerned does not conceal the further fact that under the loading indicated the mass has lost its elasticity as a steel mass will eventually lose its elasticity and will be subjected to falling apart. It is possible, then, to regard even the fixed positive elements or horsts as subject to disintegration and reduction through combined jointing and marine aggression, in other words, it is possible, in my estimation, to demonstrate a reduction of the lithosphere below sea level. As I conceive the situation we are witnessing, in short, the destruction of a continental mass through the combined effect of forces from without and from the inherent weaknesses which have been brought about through past geological conditions; that finally we have here not so much a rise or fall of land as we have of lithosphere planation or reduction upon a grand scale, and that this planation is hastened and largely induced through the weaknesses in the continental mass itself.

It may further be seriously questioned whether the "peneplain" of this Canadian area may not eventually have to be regarded as due rather to marine denudation rather than to atmospheric erosion. One of the objects of this study has been to consider the old and now somewhat neglected subject of marine denudation in connection with the modern study of joints. Further details of this will be considered later in this discussion.

Since there is stratigraphic evidence for believing in the existence of former land connection across the northern hemisphere with perhaps former water channels leading down into the present Europe and North America the question of the disintegration and degrada-

tion of this land mass becomes one of considerable interest in the physical history of the area in discussion. That the usual processes of land surface erosion and continental degradation are not enough to explain such continental destruction may possibly be a matter of opinion rather than absolute proof. However the coal beds and flora of the Pennsylvanian found in Spitzbergen, the occurrence of Mesozoic deposits across practically the area of the northern part of the hemisphere, the similarity of certain vital groups on separated areas of this vast tract of the earth argue for the existence of such a destroyed land mass, a land mass which has left its relics in the form of islands in the arctic sea, in the form of indentations and multitudes of channels and in the similarities which are to be observed in the structures of the Canadian and Baltic provinces.

The literature concerning some of these arctic islands is referred to elsewhere in this paper but from their present situation and methods of destruction I believe the explanation of the destruction of this former land mass lies essentially in two things, a definite structure in the lithosphere itself and in marine denudation or degradation; thus showing in the combination of these two elements the fact of land or lithosphere surface degradation below sea level. It is of course true that other forces such as change of sea level may be involved in this. Since the descriptions given of the marine degradation now in progress at Spitzbergen indicate a very definite joint control both in the lines of fracture and in the vertical faced cliffs caused by marine erosion acting against a jointed structure of the rock, we may explain this along precisely the same lines that the disintegration along the coast of New England and in the islands of Casco Bay may be explained, that is, by jointing and the disintegrating effect of marine and atmospheric attack. The theory that the Canadian Shield¹⁹ is a peneplain and has been so since Pre-Cambrian time, is not interfered with by this suggestion; it is rather all of it involved in an attempt to explain this and other great continental degradation upon more definite ground than the usual processes of atmospheric agents acting as the forces of erosion. I believe it is possible to show that below the zone of ordinary base leveling or peneplanation lies a still further zone of possible degradation through

¹⁹ Pirsson and Schuchert, "Textbook of Geol.," pp. 556 ff.

the destructive influence of those joints which are part of the fundamental nature of the lithosphere itself.

The old problem of marine planation which was so much discussed by the geologists of the former generation had at least elements of truth in it, elements which are, I believe, covered by the mutual action of joints and marine attack producing degradation of the lithosphere below sea level. So that marine planation does act to produce a further degradation of the lithosphere below the base level of erosion or below Davis's peneplain. That to restate the point, weathering and surface erosion proceed by the usual well observed methods and reduce the lithosphere to residual sands, clays and peneplain but this does not complete the possible further degradation of the surface of the lithosphere because the joints which have developed as one of the primary features of the lithosphere extend on down below sea level and granted an agent of transportation, for instance the sea, and its currents and tides, there is still the sub-base level process of degradation proceeding. It must be remembered that the sea is one of the most powerful reducing and transporting agents known and acts always against the continental masses somewhere, so that a system of jointing once started and the sea playing against it, the action of reduction is carried along rather quickly as geological time goes. I have personally observed in the garnet-mica-quartz schist rocks south and west of Portland Harbor, Me., the complete reduction from jointed blocks in the sea cliffs down through various stages of pebbles and gravels to sands which are composed of quartz sands and the garnet crystals from the mica schists, while the mica is by tidal action carried out beyond the shore to deeper water (Fig. 3. Plate VII).

I put some considerable emphasis upon this because the actual beach evidence and the evidence from sands and gravels on the fore-shore in many cases fail to show all the intermediate stages so that there is here suggested the possibility of many coarse and fine sands in the older geological formations having been formed by a process of rapid joint splitting, beach grinding and tidal distribution of the residue. The rapid accumulation and great diversity of sands, gravels and conglomerates of the Pottsville, for instance, may have been due to such combined action of a jointing structure and a rapid

agent of grinding. In the case of the Pottsville one of the marked features of it is the occurrence at variable intervals of massive siliceous conglomerates which alternate with fine sands and coal beds. David White²⁰ has summarized the literature in regard to the Pottsville and the following quotations are from his paper:²¹

"the Pottsville formation is in the type region composed chiefly of massive siliceous conglomerates . . . which comprises a series of ponderous conglomerates which are more variable in color, composition and assortment in the lower part and more quartzose, dense and light colored near the top . . . and are interspersed with a number of carbonaceous beds workable over considerable areas. . . . The conglomerates intercalated in increasing proportion in the upper beds of the Mauch Chunk consist of irregularly bedded poorly assorted or sometimes apparently unassorted pebble or boulder accumulations in a matrix of coarse arkose sands colored by reddish or greenish shale washes. The pebbles are mostly of quartz, though sandstone, syenite, chloritic schist, limestone and even red and green shales and conglomerate fragments are also present. Occasionally the pebbles which are sometimes subangular attain a diameter of 3 or 4 inches or more; . . ."

Further in the same report (pp. 861-863) White discusses the occurrence of these conglomerates and their possible origin and says:

"The remarkable strength and varying activity and direction of the movements of the early Pottsville sediments over the Mauch Chunk delta in the Schuylkill-Swatara region during a period of oscillating tide level are proved by the alternation and high degree of irregularity in the Pottsville beds, by the transportation of the conglomerate building material to a long distance from the present margin—i. e., by the long radius of the fan—and by the size of the boulders which are sometimes encountered far from the margin of the field. In illustration of the latter circumstance, the occurrence of boulders, 7 or 8 inches in diameter in Head Mountain, described by Rogers ('Geol. Pennsylvania,' Vol. II., pt. 1, p. 22) may be cited. . . . The interruption of the general subsidence by short periods of elevation and stability . . . accounts also for the readiness with which the conglomerated sediments, which usually almost directly, when not immediately, overlie every Lykens coal, were swept across the carbonaceous deposits on the recurrence of the general downward movement."

White, in discussing the origin of these Pottsville sediments of so pronounced a character, seems to fall back upon the idea of a rapidly depositing series of coarse sediments washed down from high lands back. (See quotations as above.) There are indicated

²⁰ David White, "The Stratigraphic Succession of the Fossil Floras of the Pottsville Formation, etc.," 20th Annual Report of the Geol. Survey, U. S., pp. 749-953 (Part 2).

²¹ *Idem*, pp. 762-763, 861-863.

here certain physical conditions which are favorable to the prevalence of jointing influence. These are the marked mechanical nature of the disintegration and the rapidity of deposit of the sediments before chemical weathering or disintegration had had time to act, the repeated occurrences of coal swamps overrun by heavily bedded gravels which indicates an unstable rock equilibrium favorable to the idea of the presence of joints; and finally the presence of subangular blocks and large pebbles and boulders shows a rapid mechanical disintegration. It would seem to be evident then that the accumulation of conglomerates, such as in the Pottsville, demand a rapid mechanical disintegration running ahead of chemical weathering, and a grinding and transporting agent to reduce the joint blocks to rounded boulders, pebbles and sands before chemical disintegration has time to occur. This, it will be observed, is practically the same idea as shown in the formation of arkose sediments generally. This point will be discussed later in connection with the similar formations in the Newark formation. This reducing agent referred to need not necessarily be marine. In the small tributaries to the Monongahela river, small streams flowing rapidly down slopes across jointed beds of sandstone, limestone and shale, I have frequently collected rounded oblong pebbles 6 to 8 inches in length and also roughly rounded rectangular blocks of limestone which are manifestly the result of surface erosion and grinding on blocks due to jointing. The shales under these conditions pass rapidly to muds and are borne along to make river flats, alluvial plains upon which river and stream ice might deposit the larger pebbles and even the angular fragments; the ability of river ice to do this is a matter of fact proven by observation. The dry summer stages of such tributary streams show many such cases of comparatively contemporary joint degradation; often the original joint structure would have to be inferred from the nature of the surface gravels if it could not be seen in the immediately adjoining hills.

In the case of marine planation there is also the further fact that an increase in the encroachment of the sea upon land masses acts in a manner analogous to the rejuvenation of a stream by elevation of the land surface, it increases its cutting and transport-

ing power and also increases the rate of land degradation. Thus the factor of jointing serves to unite processes of atmospheric and marine degradation and because it has probably done so in the past as well, it enters into the problem of paleogeography. The transgressions of the sea, the filling of old sea channels and bays by masses of jointed limestone, sandstone, or the clay rocks, material which would rather readily reduce to sands and gravels and muds, all become factors which may eventually perhaps be shown to be due to jointing degradation. The interbedded limestone conglomerates observed by Logan, Prime, Walcott²² and others certainly suggest a method of origin involving both a mechanical method of rapid erosion and also a time interval between the deposition of the original limestone layers and their subsequent breakdown to gravel or even boulder form. Anyone who has personally examined these conglomerates in York County, Pa., can have no doubt as to the angular nature of the fragments of the conglomerate and Walcott (p. 39, op. cit.) refers to the "angular fragments of limestone with sharp, clear cut edges" in the redeposited conglomerates; in some cases these boulders are "from 3 to 4 feet" in diameter, these last from Tennessee. In discussing the origin of these conglomerates Walcott believes "that the sea bed was raised in ridges or domes above the sea level and thus subjected to the action of sea shore ice, if present, and the aerial agents of erosion. . . . The inference is drawn that the debris worn from the ridges was deposited in the intervening depression beneath the sea." Walcott does not consider jointing in this connection at all though it may be regarded as a necessary adjunct for more than one reason. For one thing it is very much to be doubted if marine erosion as hypothesized could occur unless the rock masses of the limestone were already in some separated block form, ready to be torn apart and beaten about by tidal action; if on the other hand erosion against a sea cliff or against a mass of rock exposed to atmospheric weathering be regarded as having occurred we must again, in the case of limestone, believe that jointing was the predominant factor as otherwise the limestone would be reduced to weathered residues

²² Bull. U. S. G. S. No. 134, pp. 34-40; pls. X.-XIV. Especially p. 36 and p. 39.

which would be much slower in their accumulation and would hardly be in block or even pebble form at all. Secondly the elevation of the original beds could scarcely have come about without fracturing as there is no reason to suppose that the beds were so deep seated as to come within the "zone of flowage," the elevation was not probably great and would under the circumstances be included in the zone of fracture.

From the paleogeographic point of view the subject is possessed of possibly more than passing interest because of the fact that it introduces into the study of unconformity or non-conformity a means of determining the time factor, and also the means of determining the fact of a break in the succession of deposition, and it may also serve to determine the fact of a stratigraphic break without the recession of the sea. Walcott's idea of the events of the formation is practically sub-marine planation, a thing which could hardly occur without a very rapid cause of breakdown in the limestone, such as would result from jointing.

I have no desire to burden the nomenclature of the science with any new terms, but the idea of jointing causing a record of a disconformity which would otherwise be lost seems to me worth the notice. If the displacement of the lower limestones had occurred without jointing it is most probable that there would not have been enough disintegration to have left any record unless the time interval had been long enough to bring about the usual atmospheric weathering. In the physical conditions supposed by Walcott the development of jointing would also act to prevent the persistence for any great length of time of a barrier to faunal migrations.

In connection with the discussions of the conglomerates of the Pottsville above, reference is made to the arkose conglomerates and sands of the Newark. Since the granite pebble conglomerates of an arkose character are now to be observed in formation along the coast lines where rock disintegration and degradation are controlled by joints and may easily be seen to be so, as along the coast of Maine for instance, I believe it to be probable that the arkoses of the Newark of the Atlantic coast states are also due to rock destruction caused by joints, inasmuch as the sediments are composed of materials which show a mechanical disintegration always in ad-

vance of chemical weathering. In this case the destruction and degradation would follow upon the previous history of the region.

The disturbances of the Appalachian Revolution had brought about a condition in the rock masses involving both folding and fracturing. During the closing stages of the Pennsylvanian, and most probably for some time after the close of this time proper there were conditions of non-equilibrium, the position of the sea level was not probably fixed but was in an oscillatory condition. This condition of the lithosphere in that portion of the North American continent now known as the Atlantic border would involve a system of rock structures in which by successions of strains, folds, shiftings of sea level, the elastic resistance had been destroyed. The rock masses would pass by variations of uplift and erosion into the zone of fracture as well as the zone of folding. The Newark time would appear then as a time in which the strains of the previous time era had developed a great mass of fractured and jointed rock as the outer portion of the lithosphere.

The physical conditions of the continent east of the present Appalachian mountains were manifestly very different from those west. What it was that induced the great degradational movements to form the thick deposits of the Newark must be somewhat a matter of conjecture. That it was rapid is indicated by the nature of the sediments, that it did not in large parts of the area follow long periods of thick accumulation of a soil cap from chemical weathering would also seem to be a legitimate conclusion from the pronounced mechanical nature of the sediments, as the granitic sandstones for example.

The character of the early Pottsville sedimentation together with the Newark series as described from its series along the eastern states would however seem to call for an explanation based upon the idea of a quick mechanical rock destruction and transportation such as jointing would induce. The fracturing of the surface formations of the lithosphere had probably already occurred, there was needed the agent to separate and remove the segments small and great due to this fracturing. This might have been just as it is now in various portions of the earth due to steep surface drainage, glaciation or any one of the active means of transportation.

The closing stages of the Permian have been supposed to show even in North America evidences of glaciation. This may have been sufficient to explain some of the arkose sandstones but there hardly seems to be enough evidence at hand to hypothecate this as a general condition extending into the Newark. All that I am endeavoring to demonstrate is the fact of a physical condition in the surface portion of the rock structure favorable to easy and rapid disintegration rather than to try to establish any one particular means of the transportation of the broken rock fragments.

On the edges of the Canadian shield or "peneplain" as it has been called and along the edges of the continent bordering the Gulf of Maine may be seen in active operation to-day the results of a jointing structure to hasten marine erosion; this is taking place now after glaciation has removed the surface soil cap, the jointing is now fully exposed to whatever means of rock transportation may be at hand.

From the fact that practically all stages in the formation of granite sand, pebble and boulder flats may be observed in progress along this coast we may reasonably infer that the formations out beneath the low tide level extending over the continental shelf would show the marked characteristics of a marine arkose analogous to the continental arkoses of the Newark. There would thus seem to be recurrent eras of a rapid joint degradation differing from the longer periods of the usual chemical weathering and erosion, these periods following either periods of earth strains or periods in which after removal of the soil cap jointing would then proceed to a further reduction of the lithosphere.

Jointing, then, acts as a connecting factor in uniting continental and marine erosion into a process or series of processes which, so far as the lithosphere is concerned, are consecutive. Here again the real controlling factor in the degradation is the structure of the lithosphere itself, not the particular agent, because, conceivably, surface continental erosion followed by marine erosion are simply two stages of a general degradational process. There must have been in former geological times reduction of the land surfaces after the completion of a cycle of erosion; it does not follow that every

base level produced by erosion was followed by a rise of land masses and a return of the cycle of erosion, and so on to an indefinite extent. From what has just been stated previously it will be seen that I conceive these fundamental earth joints to have played an active, possibly a controlling, part in paleographic history. The connection and disconnection of land masses, the opening and closing of channels of sea migration, the filling up of channels by the rapid formation of beach gravels and tide flow; the formation of tide and sand flats and boulder and pebble flats (Fig. 4. Plate VII) such as are so common along the upper Atlantic coast line (glacial in many cases, no doubt, but still due to jointing), must all have played their parts in past geographic changes of both land and sea. The jointing which may doubtless be observed in the Alaskan coast in the neighborhood of Behring Sea, would, under these circumstances, be an active factor in the separation of land connection between America and Europe, and Asia.

Furthermore, according to this hypothesis of joint control, the destruction of a great continental mass of land across the northern hemisphere, which seems to be indicated by the fact of the relics of such a mass in the islands of the north of Europe and North America, and the distribution of islands in the Arctic Sea, all with their connected deposits of Paleozoic and Mesozoic, becomes a possibility explainable upon more definite grounds than simply the hypothesis either of sea aggressions alone or of glacial or other erosive processes alone. This continental destruction is indicated by the character of the sea cliffs of Spitzbergen and their rapid angular disintegration and the reduction of the lithosphere through a series of blocked islands which are now disintegrating under the structural weakness of joints and the transporting power of marine erosion. The details of this may be seen by reference to the literature. Thus the islands of Franz Josephs Land, Spitzbergen, and Bear Island in the Arctic Sea have been appealed to by various authors in illustration of the theory of jointing. I. D. Scott²³ and Hobbs²⁴ reproduce the figure from the original exploring expedi-

²³ *Op. cit.*, pl. 2.

²⁴ Hobbs, *Bull. Geol. Soc. Amer.*, Vol. 22, pl. 8, Fig. 2.

tion.²⁵ The description²⁶ given of the breaking down of these island masses is that of the remains of a plateau structure shown throughout the island group, with fjords which are characteristic alike of the small islands and "the mainland." Against these island remnants of a plateau carrying the remnants of the horizontal layers of Carboniferous, Permian and Miocene deposits "the sea unceasingly beats in the further destruction of the fragments of the plateau, while strange pillars and towers indicate the wide extent of the islands" destroyed in this way. This description with the illustrations given in the literature referred to shows plainly enough the destruction of the land masses by lines which are manifestly joint lines, and is fairly characteristic of similar sea coast shapes to be seen along the shore of the North Atlantic ocean both on the American and European sides.

These towers and pillars referred to are strikingly similar to some structures referred to in a recent valuable paper by Barrell,²⁷ in which the origin of certain plains along the eastern Atlantic coast is connected with former marine erosion. The discussion of this paper brings out the question of marine origin for those upstanding land masses commonly known as "monadnocks."

Those interested in the arguments for the fact of marine planation along the Atlantic coast of North America should consult Barrell's paper.

It has long been a thought of mine that it might be possible to have established some time the demonstration of "monadnocks" being residues left from a jointing structure in which mechanical disintegration had played a predominant part. As may be seen in the discussion of the paper referred to this idea is inherent in the conception of marine plains as developed by Barrell.

In the largest view of the matter Bear Island, Spitzbergen and other like land remnants are "monadnocks," if by this term is meant any residue of a former land surface which stands as a segment not now reduced to a general level. This sort of residual

²⁵ Norske Nordhavs Exped., Bd. 5; also *Peterm. Mitteil.*, 1870, S. 249 ff. Other references and a German translation will be found in "Unser Wissen von der Erde," von A. Kirchhoff, Vol. 3, pt. 2, pp. 394 ff.

²⁶ "Unser Wissen," etc., as cited pp. 395 ff.

²⁷ *Bull. Geol. Soc. Amer.*, Vol. XXIV., 1913, pp. 688 ff.

land surface is not however to be explained by ordinary land erosion, nor does marine erosion explain it any more easily unless there be entertained at the same time the conception of some structure such as the joint segments here discussed. Steep cliffs and deep fjords do not per force mean a sunken coast line primarily, they may be I conceive land or rock shapes due essentially to great joint lines.

That there exists observed evidence for believing in the ability of a jointed structure to induce a breaking down and destruction of plateaux is shown by the investigations of E. Erdmann and Nathorst.²⁸ These investigations were carried out in the structures of *Scania*, an old province in southern Scandinavia and in the opinion of so able a critic as Suess justify the opinion that

"*Scania* is formed of fragments of a great plateau broken by joints. . . . As E. Erdmann has shown the whole region is traversed by great longitudinal fractures which run from northwest to southeast; along these the whole country has been let down irregularly with the formation of troughs and horsts."

The investigations of Nathorst have shown further that this subsidence has taken place at different times,

"and that it is possible to classify the fractures according to their age. . . . In this country which has not been subjected to any folding since the Cambrian period we have a new and instructive example of the breaking down of a tableland accomplished piece by piece." (Suess, *op. cit.*, Vol. 2, p. 48.)

Some of the fractures present have been determined by Nathorst as older than the Trias.

There exists then more than simply hypothetical ground for considering jointing as one of the great fundamental shaping factors of the earth. The essential unity of the great mass of the upper portion of the northern hemisphere will probably be shown more and more as stratigraphic investigation on both the continents of Europe and America proceeds. This unity is already shown however in the similarity of structures now to be observed over widely separated areas, in the analogies if not actual parallelisms along the northern coasts and arctic lands where marine denudation is

²⁸ See citations given earlier in this paper. Their studies are reviewed by Suess in Vol. 2 of the English edition of "The Face of the Earth," 1906, pp. 46 ff.

proceeding by a method which can rationally be explained only upon the basis of some generally determining cause such as the jointing which is shown with practically universal distribution.

That such block or fracture destruction is even now proceeding over portions of the land masses is believed to be true; certain structures in the British Isles (universally regarded as remnants of the former wide extension of Europe) more especially in Scotland point to a decided indication of such block disintegration or fracturing. The approximate parallelism of the Hebrides, the Faroe, the Orkney and the Shetland islands; the same parallel indentations of the coast lines, the remarkable series of firths which find their greatest and most striking expression in the vast gash which almost cuts Scotland into two parts as the firth of Moray passes into Loch Sess and this on into Loch Linnhe and ends at length in the firth of Lorne, all these are so striking in their relations and occurrence that the conclusion is almost forced on us that here also is to be seen the illustration of a land mass passing into block disintegration by a series of fractures which exist independently of surface agents of weathering or of erosion.

As the whole mass of the northern hemisphere is contemplated in its upper parts, with its widespread likenesses, its analogies of structure and its broken remnants of former continuities to be observed in the sediments of the arctic islands and in America and in Europe, the reason for this unity of structure and unity of disintegration must be sought not in the atmospheric elements which have played upon it but must be sought for in the essential nature of the lithosphere itself.

As we journey round from lower Europe about the Canary and Madeira islands up through the British islands to Scandinavia, on through the arctic seas and islands and so on down the American coast there is everywhere shown the same disintegration of the land mass by a factor which controls all the atmospheric and erosion agents; there is seen a mechanism which whatever agent plays upon it, whether glacier, frost, expansion and contraction from change of temperature, or from the ceaseless pounding of the sea, still runs always far in advance of them all and reaching even below the level of the sea and the atmosphere determines in advance the

destruction of the land mass. This factor is the presence of joints.

Connected with the problems of the degradation of the lithosphere is the necessity of meeting the problems of the reduction of former continental masses leaving now only residues of them as islands or separated continental units such as Africa, Australia and other masses believed to have been united formerly into the Gondwana Land of authors.²⁹

Here also is to be included *Eria*, the former great continental mass extending across the northern half of the globe.

Some geologists would meet this problem by disputing in the first place the existence of such continental land masses, as Gondwana, and hold firmly to the theory of permanent ocean basins. That this idea of permanent ocean basins is a widespread and deeply rooted one is well enough known to need no special proof.

We may note, however, one reference to it from one of the older textbooks—thus Geikie:³⁰

"From early geological times, the present great areas of land and sea have remained on the whole where they are, and that the land consists mainly of strata formed of terrestrial debris laid down at successive epochs in the surrounding comparatively shallow sea."

"Without this continent, [*Eria*] on the other hand, paleontologists cannot explain the known distribution of Permian land life, and, further, its presence is equally necessary for the interpretation of the peculiar distribution of marine faunas beginning certainly with Devonian and ending in the Cretaceous."³¹

Connected with this is the related idea of a former worldwide Mediterranean, the Tethys of Suess which extended around the globe as a great encircling ocean of which the present Mediterranean is a remnant.³²

The problem then is not one which can be dismissed by disputing the matter in the first case because the weight of evidence is against such a position, and the stability of the sea floor is an hypothesis which rests more on supposition than proven fact, while

²⁹ Convenient reference may be made to Pirsson and Schuchert, "Text Book of Geology," Vol. 2, *passim*; also Suess, "Lethea Geognostica" of Frech, Paleozoicum, contains maps of Gondwana.

³⁰ Geikie, "Textbook of Geology," 3d ed., rev., p. 650, London, 1893.

³¹ Pirsson and Schuchert, "Textbook," Vol. 2, p. 761.

³² Pirsson and Schuchert, *op. cit.*, p. 761.

the belief is more and more growing among geologists that the lithosphere is governed by processes and laws which act generally to its total mass and not locally or in limited portions. Thus the idea that the laws which govern the general behavior of the lithosphere cease to act or change their character in that portion of the earth under the hydrosphere seems to me untenable in the first place and unproven in the next.

The "repeating patterns" of various authors²³ if they mean anything at all must involve some general fundamental character of the structure of the lithosphere, a character which under stresses in the mass of the lithosphere would be as likely to occur under the oceans as under the atmosphere contact. It is hardly reasonable to attempt to dismiss these repeating patterns as due to "chance,"²⁴ they are too widespread and have been too often described and identified with fundamental structures in the lithosphere. So that the principle involved in repeating patterns as indicating a definite characteristic of the lithosphere may be accepted certainly as a constructive working basis if not yet generally accepted as one of the proven facts of geophysics.

Applying then this principle to the mass of the lithosphere under the hydrosphere it should be possible to determine from the distribution of islands, volcanoes, coral reefs and other features, systems of joint control beneath the hydrosphere analogous to the systems of joint control of continental surface features beneath the atmosphere. In short the control of the lithosphere surface beneath the oceans by joints I regard as being of equal value and importance as the control exercised by jointing in the lithosphere beneath the atmosphere.

Owing to the comparative ease with which islands on the continental shelves may be shown to be parts of the masses of the continents, and, as in the very remarkable and beautiful example shown in the islands of Casco Bay in the Gulf of Maine, demonstrated to be distributed along lines governed by jointing the problem becomes really complex and more difficult of proof when con-

²³ See especially Hobbs, "Repeating Patterns in the Relief and in the Structure of the Land," *Bull. Geol. Soc. Amer.*, Vol. 22, pp. 123-176, 1911.

²⁴ *Bull. Geol. Soc. Amer.*, Vol. 22, p. 717 (discussion).

sidered in connection with the islands which lie out beyond the shelves of the continents in those portions of the oceans which are generally regarded as separate and distinct from continental structure. The connection of the repeating patterns and joints may be demonstrated from the structures along the New England coast and as it illustrates the principle referred to will be described in some detail. The particular problem here may be stated as follows: to show in the first place that the lines of distribution of the islands, bays, harbors, reefs, and other land masses in the Gulf of Maine are arranged in some definite structural relation with each other and with the rock masses of the main land, and secondly to connect this structure with processes of degradation above and below sea level. If this can be done and certain lines of uniform control shown to be present it is then proposed to apply the same line of reasoning to oceanic islands which are now not so connected with adjacent land masses as those islands in the Gulf of Maine are, and try to show that lines of jointing have been in control of the distribution of these islands; and lastly that lines of joint control being a factor in the behavior of the lithosphere we have here a general agent controlling the degradation, that is the lowering, of the lithosphere surface irrespective of whether the other agents present are variations of atmospheric or of hydrosphere contact.

Part of the demonstration of marine planation in connection with the New England coast has been rendered unnecessary by the publication of Barrell's paper just referred to; this being published after I had begun my own investigation. However, this paper establishes the point which may be regarded as of very great importance, and that is the demonstration of former widespread plains of marine origin rather than simply plains due to atmospheric means of erosion and degradation. In connection with these New England plains may be mentioned also the terraces of the Maryland Geological Survey³⁵ such as the Wicomico, Sunderland, Talbot, etc., terraces which are undoubtedly of marine origin, though not necessarily of joint control in any manner, but built on older marine plain development. It is desirable, however, for the sake of the argument to show some of the character of marine

³⁵ Maryland Geological Survey, Pliocene and Pleistocene, Baltimore, 1906.

planation at present in action along the New England coast. The data mentioned are taken from personal observation of my own and part from the published literature on the subject. Particular reference may be made to the following sheets of the U. S. Topographic Folio, namely, Casco Bay, Portland, Booth Bay, Bath, Penobscot and the following hydrographic charts, Nos. 106, 107, 315, of the U. S. Navigation Bureau, and also the U. S. Coast Pilot,³⁶ for details as to soundings, situation of reefs, bars, islands and harbors. It is not necessary to give the details of this.

The shore of the coast of Maine is almost a continuous succession of rocky points, entrant bays, steep cliffs, or outlying islands and reefs, all connected more or less by sand bars, sand dunes, necks, tidal flats or by back lying marshes. Out beyond the actual shore or strand line lie in addition successions of islands, reefs and rocky points, these all practically being composed of the same sort of rock as that exposed along the shore and with some rare exceptions are not to be distinguished from the rock masses in connection with the mainland or shore line except by the fact that these outlying masses are surrounded entirely and continuously by sea water. The topographic features about Portland Harbor and Casco Bay will illustrate sufficiently these various features. The most marked feature of Casco Bay is the extraordinary number of islands, rocky points and reefs which, as may be seen in the various publications referred to, are arranged in a general parallelism and in a northeast-southwest direction. This direction is practically the same as shown by the prevailing dip and strike of the rock masses about this portion of the Maine coast. These Casco Bay islands are so eminently arranged in repeating patterns as to suggest, even without the necessity of any actual plotting being done, definite lines of joint control, the submerged reefs as may be seen in the navigation charts are frequently continuations of the same jointing structures. If the general lines of jointing and the prevailing lines of strike be compared with some of the small islands and necks near Portland Harbor, the general connected structure of all is apparent. Thus, for example, at Prouts Neck, near Port-

³⁶ U. S. Coast Pilot, Atlantic Coast, Parts I, II., St. Croix River to Cape Ann. Washington, 1911.

land Harbor, the present distribution of islands and reefs shows the same general lines of direction and the same construction as the lines of distribution in Casco Bay. Indeed they are all parts of the same general structure. Prouts Neck itself I have determined to be a structure composed of a series of parallel reefs covered in part by glacial pebble flats, sand dunes, peat bogs, cedar swamps and contemporary pine wood; the pine woods are now growing mostly over sand dunes which lie across the old lines of parallel reefs. These lines of reefs are shown at certain intervals along the direction of the Neck and are parallel with similar lines of islands and reefs which lie out to seaward from Scarboro Beach, often appearing as isolated masses of rock, in many cases now surrounded by bogs or sand dunes. The Neck ends in a mass of rock probably formerly an island in which the same general direction of dip and joint distribution may be seen. The sea encroachment on Prouts Neck itself displays the same joint control of steep cliffs, angular block fragments and contemporary pebble and shingle beaches, such as are common on both sides of the north Atlantic coast. When these lines of Prouts Neck are plotted as to general position and direction they fall into the same scheme as shown in the other structures in Casco Bay. This cannot be regarded in any manner as accidental, but part of the same structure common to this portion of the lithosphere.

The structures around Bath, Booth Bay Harbor and similar places along the coast of Maine, are usually referred to as indicating processes due to glaciation³⁷ or are regarded as evidence in regard to a displaced coast line, all of which may be perfectly true, but it does not disguise the fact that these structures again may be plotted along a system of lines of jointing. In fact, I regard the entire distribution of islands, reefs, flats, etc., within the Gulf of Maine, not as remnants of the former surface of peneplanation, due to atmospheric erosive agents, but as structures due to the combined action of marine planation and essential lines of weakness due to jointing in this portion of the lithosphere, so that the

³⁷ See Shaler, "Geo. Hist. of Harbors," 13th Ann. Rep., Pt. 2, U. S. G. S., pp. 114-118, 1893.

repeating patterns may be carried out here into the idea of marine planation to reduce the land surface below the ordinary base level.

This, I take it, is another way of stating one of the points of Barrell's paper, referred to above, that in the plains adjacent to the New England coast upstanding structures such as the "Monadnocks" of authors, may be regarded, as the towers and figures referred to off the coast of Spitzbergen, as indicating outlines of marine planation.

I hope to discuss in a later paper some further details of this in regard to some structures about Portsmouth Harbor.

The relationship of marine planation to what has been developed as the theory of peneplains is thus a very far reaching problem. That the known action of the sea to wear away the land mass has been underestimated and neglected is perhaps due to the fact that no constant or nearly constant factor to hasten marine degradation has been taken into consideration. The reasoning of some of the older authors would seem to have been based upon the things which are to be observed only as results of local storms and also fails to consider the possible factor of the nature of the lithosphere itself as an active contributing cause in hastening the reduction of the land mass.

Some very interesting discussion of the arguments pro and con of marine denudation or degradation may be found in the various editions of A. Geikie's well-known "Textbook of Geology." Thus (3d ed., rev., p. 448) Geikie says:

"But were it not for the potent influence of subaerial decay, the progress of the sea would be comparatively feeble. The very blocks of stone which give the waves so much of their efficacy as abrading agents, are in great measure furnished to them by the action of the meteoric agents."

Taken in connection with the more recent studies in jointing as controlling rock disintegration, and in connection with what may be seen along the continental borders both land and marine the above statements will be seen to be an incomplete statement of the factors in the case.

That entire continental masses may not be seen to have been reduced by this marine planation should not prejudice the case, it is exceedingly improbable that any one agent alone has ever re-

duced any considerable continental mass; nor should the value of a factor be judged simply from the lateral extent of its spread. The investigations of Barrell already referred to would certainly indicate if not prove that marine aggression has played a most important part in the leveling of the land surface.

It may be worth while to note further that jointing is not simply a vertical matter, it seems so under certain forms of atmospheric attack but under the transporting power of a sea aggression climbing the land surface the development and the existence of horizontal joint lines will accelerate the rate of land degradation in a manner analogous to the acceleration of stream erosion due to change of level.

It is interesting that almost all of the illustrations chosen by Geikie show the controlling action of joints to shape not alone the cliffs but to accelerate the action of marine erosion yet he gives but incidental reference to the presence of joints, and seems to lay most emphasis upon the aërial agents though each illustration given shows in nearly every instance the effect of the controlling action of joints. Again I venture to state that the object of this study in most part is not to claim for either land or marine degradation the superiority as a universal agent of land surface reduction but to try to establish the fact of the presence of one factor which may be regarded as controlling both and which under conditions, favorable now to land erosion, now to sea erosion, enters as the dominant medium for shaping the resulting surface of the stony portion of the earth more technically known as the lithosphere. And that in the nature of the relation of the three elements of the earth, atmosphere, hydrosphere, lithosphere, the attempt to restrict the forces of lithosphere degradation to an assumed base level fixed by the sea level is an untenable position. Untenable because of the fractured nature of the rock mass itself and also because of the fact that the sea level is not constant, so that whether the sea level move up or down either from the shifting of the land mass or from the sea itself there will still be presented below sea level the constant factor of joint weakness in the mass of the earth itself to induce disintegration and further leveling; connecting in this manner land or

atmospheric erosion and marine erosion as two stages of a consecutive process.

There remains further the consideration of this in connection with the outlined shapes of the various continental shelves; the rapid descent of the lithosphere off these shelves being a general characteristic of all. The consideration of this subject must be with our limited information so largely speculative that it is not a subject which I now wish to discuss. The idea of attempting to carry the repeating patterns out to the sea floor beyond the limits of the shelves and to try to establish joint influence in the distribution of oceanic islands may however prove to be connected with the rise of blocked masses of the lithosphere.

It was proposed earlier in this paper to apply the method of "repeating patterns" to some island groups not connected closely to continental shelf land in order to draw a comparison if possible of similar jointing control in their distribution.

For the purpose of such comparison the following groups have been chosen though it is not by any means believed that these are the only ones which would yield concordant results; these are first the group of the Isles of The Shoals in the Gulf of Maine, secondly the Canary and Madeira group. With these for the sake of further development of the argument will be compared the islands of Oceania of the Pacific. It is not my intention to discuss in any detail the general geology of any of these groups, what it is desired to bring forth is their group morphology or more particularly the relations of their positions to each other. To consider the Shoals group first, this is a group of about seven actual islands with however a number of rock ledges which though submerged beneath the tide are an essential part of the construction of the whole group as may be seen from the navigation charts.³⁸ The figures or plotting of position are taken from chart 108.

The nearness to the present shore line of these islands with their rather evident similarity of position to other groups of islands in the same general vicinity makes no argument as to their essential connection with the mainland necessary. This is especially

³⁸ See Chart No. 108, Wells to Cape Ann, U. S. Coast and Geodetic Survey. Also U. S. Coast Pilot, Atlantic Coast, Pts. I. and II., pp. 142-143.

evident after an inspection of that portion of the waters and land masses along the Gulf of Maine. The positions of this group have been plotted by drawing lines connecting the greatest numbers of the islands including reefs which are regarded as islands. While the distribution of these islands is not so striking as the islands of Casco Bay to the north and east yet it is apparent that the application of the repeating pattern establishes here the existence of a fairly regular system of jointing which may be stated to control the position of this group as a series of upstanding residues of erosion from an older land surface, a small illustration of the more widely known case of the British Islands as remnants of a former series of connected structures all part of the mass of the continent of Europe.

With this plotting of the Shoal Islands may be compared the plotting of the positions of the Canary-Madeira group. I have used for this the map from C. Gagel³⁹ in his discussion of the islands of the middle Atlantic. (These were shown by lantern slides while reading paper.) The arrangement of practically all of these Atlantic islands shows lines of a parallel grouping so very similar to the development of continental volcanic vents and fissures along lines of separated segments or joints that it will hardly be disputed that the same principle has worked in each case. These islands consist in part, according to Gagel, of volcanic cones built up from the floor of the sea and in part are "broken remnants of the European-African continent."⁴⁰

According to Gagel three of the Canary group, namely La Palma, Fuertaventura and Gomera "show the undoubted representatives of very old volcanic, archean and sedimentary formations, which form the true sockets (= Sockel) of the islands and prove themselves to be part of an old great continent, whose shattered fragments still appear in these islands." The other islands of this group consist of recent volcanic eruptives of Tertiary or Quaternary age carrying in some instances portions of marine Tertiary

³⁹ C. Gagel, "Die Mittelatlantischen Vulkaninseln," in "Handbuch der Regional Geologie," Vol. 7, part 10, Heidelberg, 1910, pp. 1-32. Here will be found the literature for this group noted and original references given.

⁴⁰ *Op. cit.*, p. 31.

sediments and in other cases as on Tenerife, Hierros and Antaos, the incoherent volcanics carry loose fragments of "older or at least coarsely crystalline rocks" which Gagel considers may have come from an older deep-seated "socket" or portion of the islands.

There is presented here then a construction in which may be seen two phases of joint influence, the broken and more or less symmetrically arranged fragments of residues of a continental structure, and secondly the rise of volcanic masses to the surface through the open fissures which lie between the aforementioned segments.

The Azores show likewise recent eruptive products with apparently no sediments earlier than middle Miocene; there is the further fact of deep sinking of the sea floor between some of these islands, as over 6,000 feet between Graciosa and Corvo.⁴¹

The general position of all these island groups of the Atlantic, their relations to the surrounding lithosphere shapes are all of importance; the positions of the Canary-Madeira group near the great adjustments incident to Mediterranean conditions, and the position of the Azores on the great Atlantic plateau are part of the general idea that these are all structures which are to be regarded as behaving in the same way as similar structures do on those portions of the lithosphere which are now continental. There are here evidences of the controlling action of a system of joints which are believed to have played their part not in surface degradation in the usual sense, but have been active in a system of movable segments which when under stress have resulted most probably in an essential up and down movement.

I have attempted to demonstrate block or joint development in the first place as an integral part of the lithosphere itself in a manner analogous to its presence shown in the larger land masses. That it has been the controlling factor in the disintegration of a former land mass represented by the islands now under discussion is too much to take as anything which can so easily be demonstrated. That it has been an active factor in marine denudation at this locus seems to me rather more than a supposition and appears as probable from the action of joint planes to produce an acceleration of marine degradation elsewhere. If these ideas be carried to the island

⁴¹ Gagel, *op. cit.*, p. 9.

groups of the Pacific such as the Solomon, New Caledonia, Kermadec, New Zealand groups there will be found an arrangement of island masses which have for many years suggested to geologists definite plans of group arrangement. It is not needful to detail these here as they are too well known to need review, having been considered so often in connection with the origin of coral reefs; a recent bibliography has been published by P. Marshall.⁴²

What seems to the present writer one of the most suggestive of recent theories in regard to these island structures in general was put forth by Alexander Agassiz in various studies published in the *Memoirs of the Museum of Comparative Zoology*.⁴³

As is of course well known the main ideas concerning coral islands in the Pacific have centered about the ideas of subsidence and numerous suggestions have been offered to satisfy this requirement. Agassiz in 1898⁴⁴ in discussing the reefs about Australia expressed the idea that too much emphasis had been laid upon subsidence and wished to bring in the factor of marine planation with "terraces of erosion" upon which coral masses would by natural extension grow together and form the Great Barrier Reef.

In later writings (*Memoirs*, Vol. XXVIII.) Agassiz has again cited marine erosion as developing the platforms upon which the reefs of various sorts would develop.

Given a water condition favorable to coral life there is no doubt that coral life would start along the rocky structures of the north Atlantic just as is now to be seen in the warmer seas. The problem here is not the coral life but rather the development of a platform upon which the coral organisms may persist. There can be little doubt that coral reef developments of various sorts would be found today along Madeira-Azores groups if the water conditions were favorable.

I would wish to suggest then that a profitable field for further study of coral life in the field in the Pacific islands may be found

⁴² P. Marshall, "Oceania," "Handbuch der Regional Geologie," Vol. 7, pt. 2, Heidelberg, 1911. Reference may also be made to Suess, Dana, A. Agassiz, Murray and many others.

⁴³ See particularly *Mem. Mus. Comp. Zool.*, volumes from 1898 to 1903.

⁴⁴ *Bull. Mus. Comp. Zool.*, XXVIII., 1898; see also Agassiz, *Mem. Mus. Comp. Zool.*, XXVIII., 1903.

in the more careful study of these islands as developments from jointing or segmented structures.

The marked character of volcanic products from the island volcanoes, such as the successions of andesitic lavas supposed to be characteristic of the Pacific type compared for example with those from the Philippines which are much more varied though frequently andesitic, and with those from the Sandwich group which are essentially basic, may perhaps show some solution to the physiographic development of the region indicated.

That the igneous history of some of these groups has been a very long one is indicated by the same sort of reasoning as applied to rock masses elsewhere. This may be taken to mean a long period of time in which the segmented condition or open fissure condition has prevailed.

It is not accidental nor casual but from the evidence at hand we may with reason conclude that the surface of the lithosphere beneath the hydrosphere in this Pacific district of Oceania has been subject to tectonic movements, fissuring extrusion of igneous masses in a manner analogous to other parts of the lithosphere such as continental masses in which a jointing or block structure may be shown to be present.

Connected with this discussion is the general structure of the solid portion of the earth, now commonly referred to as the zones of fracture and flowage. These, as is known, are divided into more or less definite lines so that under certain supposed pressures rock masses will move in flow lines rather than in fracture lines, such as is indicated in many diagrams of mountain making. This may be regarded by some authors as a factor against the proposition of joint control which I have proposed. Further reflection, however, will suggest the thought that while the zones of fracture and flowage do represent definite differences in the behavior of the rock masses of the earth, that these lines of zone are not, however, fixed in their actual distance below the surface of the lithosphere. In other words, it is not only possible to conceive but I think the circumstances compel us to conceive of a certain rock mass passing from the flowage zone to the fracture zone by release of pressure. That is, if we take certain types of mountain structure represented

by the conventional lines of anticline and syncline structures,⁴⁵ a geosyncline, for example, or anticline would develop into a series of fractures in the outer portion of the lithosphere if the pressure which made the original fold were to continue or were to be applied without a heavy series of overlying beds. The zone of flowage would become a zone of fracture by release of pressure from above without necessarily there being a release of other strains in the mass of the rock. To make a practical application, the Appalachian folds and the fan-shaped folds of Heim, in the Alps, are often represented in diagrams as having developed as surface folds of the lithosphere, that is, it is practically stated that we might conceive a portion of the outer lithosphere structure to be practically destitute of faults from the fact that the rock structures under pressure assume a fold-flowage structure. Thus, in Fig. 285, in Pirsson & Schuchert, p. 362, the evolution of the Appalachian mountains is represented as having occurred as a series of zones of surface folding followed by erosion of the folded zone producing the usual peneplane. This I conceive to be at least an unlikely series of developments in spite of the weight of the authority back of the theory.

If the pressures which developed the Appalachians took place in a mass so that folding and flowage took place, we would almost of necessity have to suppose a heavy super-incumbent mass of rock, so that instead of fracturing taking place the rocks under the intense pressure would move by lines of flow; on the other hand if the above pressure were applied to a mass of rock without this heavy overlying weight, then fracturing would almost certainly have to follow. So, if in such a mass as the Appalachians where the force of the uplift continued through a long period of geologic time, with processes of surface erosion proceeding, it is an allowable supposition to believe that the zone of flow would pass upward into a zone of fracture and expose the outer portion of the lithosphere to a much more rapid means of degradation than would follow from the usual processes of erosion and degradation on an unfractured mass. So that the zone of flowage in this case, and it would apply to other

⁴⁵ See, for example, Figs. 285-291, Pirsson and Schuchert, "Textbook of Geology." Also Dana and others.

uplifted or folded areas, may be imagined to pass into a zone of fracture by a lessening of the distance between the outer atmospheric contact and the mass of rock in question. I do not wish to complicate the discussion by citing hypothetical cases, but we may perhaps legitimately imagine that folded areas such as the Appalachians and the Alps would continue to be subject to earth strains after erosion had removed a considerable part of the overlying weight of rock mass. This would then allow these folded masses to pass into fractured masses of various degrees of intensity. The bearing of this on joint control of degradation is, I think, obvious enough.

In connection with other courses of the rock mass of the earth which are not subject apparently to these intense pressures, such as the Canadian Shield, I have already stated that I believe the source of fracture there to be the successions of overloading by sedimentation, ice accumulation, marine inundation, with the consequent wearing out of the elasticity of the original rock mass. The rock mass under these circumstances would then simply proceed to fall apart, depending upon the presence of some agent such as marine erosion capable of removing the blocks due to jointing. The illustrations given of the disintegration of the mass of the coastal plain near Ogunquit, Me. (Figs. 5-6. Plate IX) will show practically how a mass of folded rocks will when exposed to release of pressure break down into segments which can easily be seen to be the result of wide reaching joints. Almost the whole coast of Maine is an illustration of this.

As for these rocks near Ogunquit, they show all the marks of what is usually referred to as rock bending under pressure, S-folds are not uncommon, isoclinal folds are evidently quite frequent and it is a very probable supposition that here is a mass of rock which has been under such stress that distinct folds developed and that now very definite lines of jointing are in control of the lowering of the land mass.

It is of course entirely possible or even probable that some of this jointing was simultaneous with the folding. I hope in a later paper to discuss the evidences for this.

But the essential fact stands out that here is a portion of the

stony portion of the earth passing into complete disintegration under the combined action of a great system of jointing which has already broken down the coherency of the mass, and under marine transportation (erosion).

It is my expectation in a later paper to present further results of the study of this locality.

From the discussion given, there may be deduced, then, the following propositions:

Proposition 1a.—That the lithosphere has certain constant physical factors which act universally and independently of local surface conditions: one of these is, for example, igneous action, and another is jointing.

Proposition 1b.—That this jointing develops as an essential result from the nature of the lithosphere itself which shows in practically all cases from continental masses to loose sands the regularity of lines of weakness.

Proposition 2a.—That surface features of the lithosphere, both sub-atmospheric and sub-oceanic, are controlled not by the agents of the atmosphere nor hydrosphere, but by the distribution of lines of master and minor joints.

Proposition 2b.—That surface drainage, glaciation, variations of weathering, may be regarded as accidental; that behind all of them, and also running ahead of them as the essential controlling factor, is jointing.

Proposition 3.—That joints have been present throughout all the geological history of the lithosphere, considered as possessed of solid portions.

Proposition 4.—That in the development of continental outlines, including continental shelves, and also in the development of surface continental features due to weathering and to atmospheric and marine erosion, the controlling factor is not atmospheric nor climatic nor marine primarily, but is due to the fundamental nature of the lithosphere itself as shown in its lines of jointing.

Proposition 5.—That the "repeating patterns" of authors which show joint control of the lithosphere on the continental surfaces may, with equal truth and value, be applied to the interpretation of the sub-oceanic lithosphere and that the distribution of oceanic

islands, volcanoes, reefs, and so on, may be explained by joint control of the structure of the lithosphere.

Proposition 6.—That jointing being a constant factor in the structure of the lithosphere and producing lines of easier displacement than folding, is one of the fundamental factors in the shifting of land and sea level, whether the shifting be regarded as having taken place under the hydrosphere or in the continental masses.

Proposition 7.—That jointing should be regarded by students of geophysics as an essential dynamic and constant factor in the behavior of the lithosphere and that it has been so practically throughout all geologic time.

Proposition 8.—Base line or base level of erosion is a term which refers to the results of atmospheric degradation and does not express the final results of continental land surface reduction. Since the relative positions of land and sea are known to be subject to change without any essential change in the character of the rock masses sea level can not be used as a term to express the equivalent of the lowest limit of continental land surface reduction or degradation. .

From this there may be deduced principles which are proposed as a

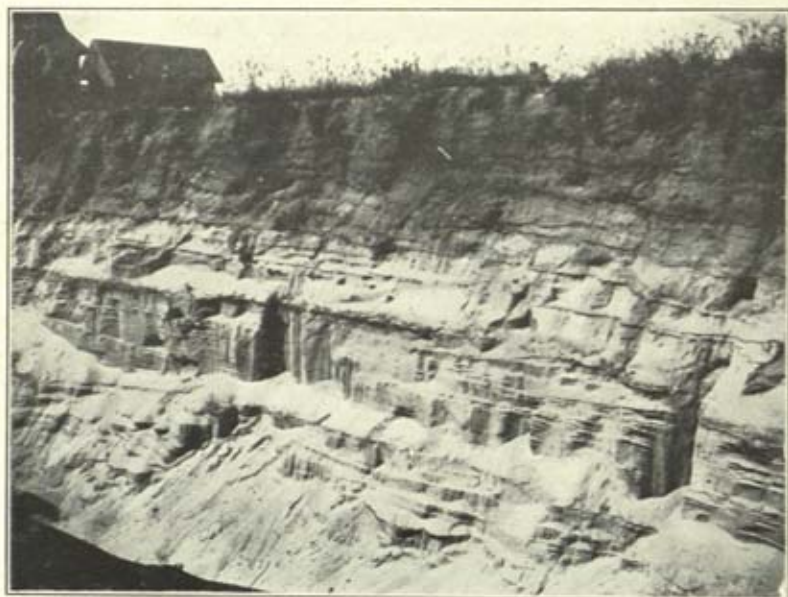
LAW OF JOINTS.

1. The lithosphere is subject by its nature to the development of lines of weakness or fracturing which in turn develop into actual movable segments.

These segments or joint lines develop in such regularity of arrangement that they may be said to occur in "joint-systems" which are shown at the surface as controlling agents in land erosion and land shaping; and they act beneath the surface inducing tectonic movements which are independent of atmospheric or marine contact.

2. Degradation of the lithosphere is fundamentally a factor in its own structure and will occur whenever an agent capable of transporting the movable joint blocks is in contact with the lithosphere.

This applies to those portions of the land or rock mass below sea level.



FIGS. 1 AND 2. TWO VIEWS OF SYMMETRICAL DISINTEGRATION OF SANDS IN BEACH TERRACE AT REHOBETH BEACH, DELAWARE. THE SANDS ARE UNCONSOLIDATED; THEY OVERLIE THE TALBOT FORMATION. (PHOTOGRAPH BY AUTHOR)





FIG. 3. JOINT DISINTEGRATION, PROUT'S NECK, MAINE



FIG. 4. JOINTED-BOWLLER FLAT, SEA POINT, MAINE



FIG. 5. BLOCK JOINTING IN FOLDED AREA NEAR OGOQUIT, MAINE



FIG. 6. ANGULAR TERRACE IN ROCKS, MASS SHOWN IN FIG. 5

3. Atmospheric erosion and marine planation are two separate phases of a general process of lithosphere degradation which are frequently connected into consecutive stages by the presence of joint lines which extend from beneath sea level up into the mass of the lithosphere above sea level; these lines are also horizontal and thus act to produce flat surfaces.

4. Degradation of the lithosphere surface may occur also by the vertical displacement of these joint segments irrespective of atmospheric or marine contact.

5. Joint control of lithosphere degradation has been active since the period when the lithosphere possessed a solidified structure and has been a fundamental factor in the evolution of the lithosphere, or geomorphology.

DETAILED OBSERVATIONS ON PLATES VI.-VIII.

PLATE VI., FIGS. 1 and 2. These sands are entirely unconsolidated but are rather gritty. Rehoboth Beach, Delaware.

PLATE VII., FIG. 3. Joint disintegration in quartz-mica-garnet schist, Prouts Neck, Maine. The loose segments fall to water level and through a pebble-gravel process are reduced to quartz and garnet sands, the mica washes to sea. The original rock character is thus totally destroyed by a rapid mechanical action working through joints.

FIG. 4. Boulder flat at Sea Point, Maine, above Portsmouth Harbor. This flat is composed of incompletely reduced joint blocks from the adjacent rock masses and appears to be built out over a reef which lies parallel to a series of other reefs and small rock segments in place. The flat is a prolific breeding and feeding ground for vast colonies of mollusca, small crustacea, lime secreting algae, *Laminaria* and other forms of animal and plant life. Angular blocks coated with lime carbonate are frequent. The relation of such boulder flats to life distribution suggests interesting paleographic analogies.

PLATE VIII., FIG. 5. Block disintegration proceeding in a folded area in coastal plain. The folds are now to be seen with their tops in most cases cut off and are broken into blocked segments. This fracture may be seen to extend below the level of the cliff. Near Ogunquit, Maine.

FIG. 6. Angular edges forming an abrupt series of sea terraces. The entrance of one of a series of parallel coves or small bays may be noted. In front of the cliff extends a broad platform induced by the horizontal jointing. Cliffs near Ogunquit, Maine.

(All of the illustrations are from photographs taken by the author.)

SIGHT AND SIGNALLING IN THE NAVY.

By ALEXANDER DUANE, M.D.

(Read April 13, 1916.)

Perhaps a better title for my paper would have been "Desultory Notes of an Ophthalmologic Signalman." Such a title, moreover, would indicate the paper's only excuse for being. For desultory as the notes unfortunately are, the author has felt that they might be of some service because, being both an ophthalmologist and a signalman, he had a somewhat unusual advantage in studying the subject. As an ophthalmologist, he had been concerned with the observation of visual phenomena and knew something of the physical and psychic factors underlying them; while as a signalman, quartermaster, and signal officer in the naval militia and navy, he acquired a practical acquaintance with the various forms of naval signalling under service conditions.

In considering the subject it is important to have some idea of what constitutes naval signals and to know in general how they are made and interpreted.

For the purpose of this paper, signalling may be defined as the art of communicating with another person by means of symbols other than written or spoken words; such symbols consisting, according to the method employed, of shapes, lights, sounds, movements, or any sort of exhibit whatever that can be appreciated at a distance. These symbols, either singly or combined in groups, are used, according to some special system, to denote individual letters, digits, or other characters; and these characters in turn are combined according to some preconcerted code to form messages.

The special symbols employed in any one system are called the elements of that system; and the system is said to have 2, 3, or 10 elements, according to the number of different kinds of symbols used in it to form the letters or characters. Thus a signal consisting of a display of lights vertically over one another at a ship's mast is said to be made by the Ardois Method. It is made with two elements, since only two kinds of symbols (*viz.*, red and white lights)

are employed. These elements are combined according to the International Morse System to form letters; and a succession of such letters may form an arbitrary combination to be interpreted by the Navy Code.

METHODS OF SIGNALLING.

The methods used in navy signalling are as follows:

(a) *Motions.*

Wig-wag (movement of flag, torch, search-light, or other object from side to side).

(b) *Flashes of Light.*

Flash lantern and winker light.

(c) *Colors, Fixed or Moving.*

Display of colored and white lights (usually several in one display) (Ardois Method).

Projection into the air of rockets or red and green stars (Very Method).

Coston and other lights.

(d) *Forms.*

Cone, top, and drum.

Square flag, pennant, and ball.

Semaphore.

(e) *Forms and Colors.*

Hoists of colored flags.

(f) *Sounds.*

Steam whistle, bell, gunfire.

Telegraph (usually wireless).

SYSTEMS OF SIGNALLING.

The systems commonly used in naval signalling are these:

Dot-Dash System.—Comprises two or usually three elements,¹ viz., right, left, and front motions (Wig-wag); short, long, and extra long flashes (Winker Light, Heliograph); red and white lights (Ardois); red and green stars and rocket (Very Method); short, long, and extra long (or single, double, and triple) sounds (Sound

¹ Really in these systems there is a time interval (between letters) which constitutes a fourth element.

Signals). Two of the elements are combined to form letters according to the International Morse Code, and if there is a third, this is used to form an interval or make some special signal.

Semaphore System.—Comprises 8 elements, viz., the eight positions of each of the two arms of the semaphore (or the two arms of a man). Combinations of these according to a special code form the various letters of the alphabet and special signals.

International Hoist.—Comprises 27 elements (flags denoting 26 letters of the alphabet and one answering or code pennant).

Navy Hoist.—Comprises 45 elements, viz., the 26 alphabetic flags of the International System and 19 others (repeaters, guide, recall, position, etc.)

International Distance System.—Comprises 4 elements, viz. cone, top (inverted cone), drum, ball. (A square flag may be used for cone, pennant for top, a pennant tied back to halliards or a flag tied in the middle for a drum.) These combined according to a special system form letters and special signals.

Navy Distance System.—Comprises 3 elements, viz., cone, top, and drum. These combined according to a special system form letters and special signals interpreted by the Navy Code.

SIGNAL CODES.

Signal codes are divided into two great classes, Alphabetic and Signal-Book Codes. In an *Alphabetic Code* the letters or digits indicated by the special system employed have their actual value as letters or digits, and are further combined to form words and numbers just as they are in ordinary writing—to form, in other words, what we may call spelling messages. In a *Signal-Book Code*, the letters indicated by combining the elements in the system used are mere indexes referring to special messages or words contained in a code-book. Thus the elements 1, 2, 3, of the dot-dash system, when used in its ordinary way as an alphabetic code, would if combined thus, 22 2122 3, denote the actual letters M Y, spelling the word MY. But the same letters whether sent by the Dot-Dash System, the International Flag System, or the International Distance System would, if interpreted by the International Code, have no mean-

ing as letters, but would denote the message "Ship disabled; will you tow me?"

The following codes are used:

Alphabetic Codes.—Unless notice by special signal is given to the contrary, all messages sent by wig-wag, Ardois, telegraph, winker light, and semaphore are spelling messages. All of these are interpreted by the International Morse Code except the semaphore, and this is read by the semaphore code. In certain cases the flags of the International System may also have their alphabetic meaning and be used to form spelling messages.

Signal-Book Codes.—All messages sent by flag hoist, shapes, steam-whistle, and Very stars, and occasionally² messages sent by other methods are code messages, to be interpreted by special signal codes. These signal codes are the—

International Code used with the International Flag Hoist. It includes the slightly variant code used with shapes for sending International Distance Signals.

Navy Code used with flag hoist, shapes, steam whistle, and Very stars. The regular Navy Code includes battle signals, general signals, boat and deck signals, and speed signals. To these may be added the towing, running, and riding lights (International), buoy and lighthouse signals (U. S.), storm signals, and the various officers' and national flags.

Of course a message, whether a spelling or code message, may be transformed by cipher, previously agreed upon or denoted by the signal sent.

WHAT A SIGNALMAN HAS TO DO.

The signalman must have an intimate working knowledge of eight different methods of signalling (by wig-wag, light flash, Ardois, Very stars, sounds, shapes, semaphore, and flag hoist) to be used according to six different systems. He must know with absolute certainty the signification (often multiple in each case) of some 30 combinations of right and left movements, 30 combinations of red and white lights displayed over one another, 30 combinations of red and green stars projected into the air, 30 combinations of short and long flashes or of short and long sounds, 30 different positions

² When preceded by the special call meaning "signals follow."

of the semaphore, and some 50 different flags, not to speak of the various national flags. In addition, he must know the various day and night position and speed signals, danger signals, truck light, side lights, and weather signals, the different kinds of buoys and beacon lights, and must be able and ready to pick up boats, ships, and rocks. He is the "eyes of the ship" and on his vigilance and sight, speed and accuracy, the ship's safety may largely depend.

The signalman's duties then are both highly important and also are varied and complex. They demand a considerable degree of intelligence and skill. In this as in all other skilled work, experience and practice count enormously. To an outsider it is amazing to see the facility with which an experienced man can fulfill all these duties and carry them on for a long time without apparent mental and physical fatigue. One signalman, who did not claim to be specially proficient, told me that he once read visual signals without intermission for two hours and a half, and when his work was done felt no more tired than if he had been reading a book for the same length of time. Yet during this long period eyes and mind must have been intent with scarcely a moment's respite on ever-varying combinations of symbols. And the quickness with which signals are appreciated and the necessary responses given is equally astonishing. For example, when in squadron evolutions a flagship is setting flag signals, the flags, bent on to the halliards, do not, of course, break out so as to be visible until they are started on their way up. Yet it is no uncommon thing for every ship in the squadron to send its answering pennant up before the flagship's display has reached the top, thus showing that in two or three seconds at the most the four or five flags comprising the signal have been read, understood, and answered by every signalman—and that even when some of the ships are several miles away.

Such expertness, of course, comes only with practice. The beginner not only discerns signals less readily, less far, and particularly with less certainty than the expert, but he tires soon, so that his work quickly becomes unreliable.³ Now even in time of peace,

³ Recognizing this, a quartermaster will not keep an inexperienced signalman looking too long, especially through a field-glass, at a semaphore or winker light, but will relieve him after a few sentences have been taken. So

but, of course, much more in time of war, the exigencies of the service may be such that the skilled man is not available. He may have to be replaced by a man not sufficiently trained. This is particularly the case under present-day conditions when our warships are deplorably undermanned. It is important, therefore, to consider what difficulties an inexperienced man has to contend with and how these difficulties affect his reading of signals.

There is another aspect of the matter. There are some men who never become good signalmen. The practice has been to discover whether this is so or not by selecting a man haphazard, trying him out, and rejecting him if he fails. It would be better surely to be able to form some idea in advance of what the causes of disqualification are, so that the right sort of man might be picked out in the first instance and no time wasted in training the inefficient.

From both points of view it becomes us to consider the factors that determine a man's ability to perform signal duty. These factors are: (1) The character of the signals themselves and the way this character is affected by external conditions. (2) The signalman's own physical and mental qualifications.

INTRINSIC CHARACTER OF SIGNALS THEMSELVES.

Signals differ very greatly in:

1. *Visibility*.—Some even under the best conditions can hardly be seen beyond two or three miles (by the tyro not so far), others can be seen any distance.

2. *Legibility*.—Some signals, especially those having a large number of elements (flag signals) or in which the elements are shown in groups (Ardois) or very rapid succession (semaphore, hand wig-wag), can usually be seen further than they can be read—although it must be stated that this discrepancy between legibility and visibility is most marked with beginners and diminishes rapidly as experience grows. Other signals (winker light, wig-wag by flashlight or searchlight, Very stars) can be read even by beginners as far as they are seen.

3. *Amount of Strain They Impose on the Sight and Attention*.—

also a signalman, when finding himself getting unsteady, will ask a companion by him to take his place.

This is particularly great with the semaphore and especially the winker light.

EXTERNAL CONDITIONS AFFECTING SIGNALS.

These are:

1. *Faulty Technique in Sending.*—Mistakes may occur with any method; but faulty technique gives trouble particularly with the hand wig-wag, hand semaphore, and winker light. It affects visibility scarcely at all, but often greatly reduces the legibility of messages. By impairing legibility it puts an added strain on the sight and attention of the observer.

Faulty technique includes not only carelessness in the mechanical execution of the signal, but also failure to acknowledge signals properly, failure to secure a proper background when requested, failure to correct errors, and too slow sending. Such faults, if persisted in, unduly prolong the message and weary the receiver.

2. *Weather Conditions.*—These naturally affect both visibility and legibility, especially the latter. Flag hoists and Ardois become particularly difficult to read in thick weather and may have to be replaced by distance signals or even by sound signals. Flag signals, if the ship is not under way, require some breeze for their proper display; but a gusty wind may interfere a good deal with their legibility.⁴ The sun, if behind the observer, is usually a help especially in hand wig-wag, hand semaphore, and flag displays. The light shining on the display and reflected from it, makes the signal stand out better, especially when the latter is in motion or shows contrasting colors (hand wig-wag, hand semaphore, flag signals). Per contra, the sun behind signals not only tends to drown them out so that they are hard to read, but also causes so much irritation and dazzling as the result of *glaré*, that the eyes may soon tire and become unserviceable.

A strong wind blowing in the observer's face may make the eyes water and so interfere with the reading of signals.

3. *Use of Field Glass.*—Some signalmen prefer to use the naked eye, but many habitually use either a spy-glass or generally a low-power field glass. This about doubles the distance at which signals can be read and increases the legibility of some signals, espe-

⁴ For the tyro at least. The older and more experienced man will find little trouble on this score.

cially the night semaphore. When, however, the ship is rolling or pitching a good deal, it is difficult to keep the glass on the object. It then becomes quite hard to read the signals, and the strain on the attention is considerably increased. And even when there is no motion the use of a glass causes more strain than looking with the naked eye.

4. *The Motion or Position of the Ship.*—This not only makes the use of a glass difficult, but even with the naked eye interferes with the observation of signals. So too, the ship may be so placed that flag or semaphore signals are not easily seen or have a poor background.

5. *Occlusion of Object* by spars or funnels or by the sudden dipping of the ship in a heavy swell.

INFLUENCE OF THESE CONDITIONS IN SPECIAL CASES.

The visibility and legibility of the chief methods of signalling and the demands they make upon the eyesight may be summarized as follows:

1. *Hand Wig-Wag.*—The regular wig-wag signal kit comprises two-foot, four-foot, and six-foot flags, white, red and black. The black flag is supposed to be used with a sky background, but is rarely employed. The red flag theoretically would show better than the white against a green or white background, but, as a matter of fact, the white shows best under almost all circumstances.

The wig-wag is visible a very considerable distance. Its legibility varies very greatly with the technique of the sender and with the background. Given a good sender and a good sky background, the wig-wag messages with the large flags can be read over six miles* even with the naked eye. This method requires close attention, but is not particularly tiring to the eyes.

Very legible is the night wig-wag with oil or electric lantern.

2. *Wig-Wag by Searchlight.*—A searchlight projected against a cloud and waved from side to side like the hand wig-wag, can be seen and read practically any distance. Vessels have signalled in this way from ocean to ocean across the Isthmus of Panama—the

* The statements in this and the following paragraphs regarding range of visibility are to be taken as the maximum for expert receivers. For ordinary signalmen, particularly when the weather conditions are not good, these distances would be halved.

ships being forty miles apart. The messages are very legible and the method not taxing to the eyes.

3. *Hand Semaphore*.—This has largely replaced wig-wag, because the signals can be made faster. I am a tyro at it myself, and for that reason, perhap, it seems to me more difficult and less legible than the wig-wag. It certainly requires careful technique, otherwise certain combinations are indistinguishable from each other (*e. g.* O from I and W from X). It is said that a good observer can read signals three or four miles, but this depends greatly on the sender and the background.

4. *Machine Semaphore*.—By day the semaphore arms are readily seen if the background is good. By night the lights on the two arms are apt to blend in the acute angled signals (H, O, T, W, Z), making it somewhat difficult to determine whether one or two arms show. This difficulty does not obtain when a field-glass is used. If the night semaphore is worked rapidly, the after-images produced by one display might theoretically be confused with the display following, but this seems not to occur. The shifting lights are somewhat trying to the eyes of the inexperienced. The range of legibility is variously stated at one to three miles or more.

5. *Winker-Light*.—This, like the heliograph which it greatly resembles, can be seen practically any distance, provided the sender or receiver is sufficiently elevated above sea-level and intervening obstructions. If the technique of sending is good, the light-flash can be read as far as it can be seen. In India, where sending can be done from great elevations, the heliograph, they say, can be read a hundred miles. I have signaled with it sixteen miles. It might be used that far on shipboard. To do so would require both observer and sender to be rather more than forty feet above sea-level.

The winker light is quite trying to the eyes, especially when received through a glass, and beginners cannot receive long at a time without their attention flagging and their work being unreliable. Twinkles and flashes⁶ impinging in rapid succession on a partially dark-adapted eye, cause considerable strain, although it is a strain to which one does get remarkably accustomed.

Just as the searchlight is used for wig-wag it is also used for

⁶ Readers of Kipling will recall his graphic lines:

"A heliograph *tempestuously* at play."

throwing dots and dashes of light against a cloud. Such signals, which are the same as winker-light signals, can be seen and read practically any distance.

6. *Ardois Signals*.—The Ardois is not as fast as the semaphore, but faster than the winker light or wig-wag. The signals are easily seen and easily read. Observers differ a good deal as to the range of visibility of the Ardois—some alleging that it can not be read more than three miles under the most favorable conditions, others that it can be seen from four to six miles. This is with the electric lamps on shipboard which are slung twelve feet apart. In some experiments that we made at our Fire Island signal station during the Spanish-American War, similar lamps lighted by acetylene were read eight miles.

At long distances the several lights of the display run together into a continuous bar, but even then it is possible to read the signals by noting whether the bar is long or short and whether it is plain red or plain white, or white beaded with red. The red light naturally looks smaller and dimmer than the white, and it would doubtless be an advantage if the red lamp were made larger and of more candle-power so as to equalize the visibility of the two.

The Ardois displays may be obscured by funnels, masts or other interventions; and it sometimes happens that in the complex of wires that go from the keyboard to the lamps some part will give out, so that one or more of the thirty combinations is defectively given.

The Ardois makes very little tax on the eyes.

7. *Flag Displays*.—Flags of battleship size can be read six miles or more by a practiced observer. This, however, obviously depends on many factors—the clearness of the atmosphere, the direction of the sun,⁷ the way the flags blow out in the wind,⁸ the character of the background, etc. The colors used are white, red, blue, yellow, and black (the last in only three of the flags). White is by far the most conspicuous color, and in the party-colored flags may be the only part visible. Some, in misty days or at dusk, find difficulty in discriminating between certain flags like L and U but the experts say they never have trouble on this score.

⁷ Sun behind flags interferes very seriously with the ability to read them.

⁸ A little flapping enhances the legibility of the flag; a good deal of flapping impairs the legibility.

Flag signals, being necessarily intermittent, make no great demands on the eyesight.

FACTORS IN THE SIGNALMAN HIMSELF.

The factors that may affect a signalman's⁹ efficiency are:

1. Faulty vision.
2. Defective color vision.
3. Refractive errors, including defective accommodation.
4. Muscular errors.
5. Slow reaction time.
6. Slow adaptation.
7. Effect of after-images.
8. Fatigue from prolonged, excessive strain of eyes and body.

1. *Faulty Vision*.—Fortunately in our navy, owing to the insistence of the medical officers, the visual requirements are high, so that seamen generally, and hence the signalmen also, must have good vision in each eye without the aid of glasses.¹⁰ It is very important that this standard be maintained. I may add that it is a great pity that the same standard has not been maintained in the army. In the conditions of naval service and of army service too, acute vision is important, and glasses are a considerable handicap. Readily fogged by moisture, smoke, or grease, they may obscure the vision just when it is most needed. For in quick signalling, when a second or two lost may mean the loss of a message and the consequent delay of a whole squadron in some important evolution, one has not time to clean glasses or replace them when broken. And if one pulls the glasses off and goes on without them, the sudden change in visual acuity and the sudden strain on the accommodation thereby produced may, even with no very great refractive error, reduce the sight below service requirements. I myself had a good example of this during a week's cruise on the San Francisco in 1896. Without glasses I had a vision of some $\frac{20}{80}$ to $\frac{20}{40}$. Soon after the cruise started my glasses were broken. When it came my turn to act as gun-pointer, I could not see the target; when I took my place

⁹ What is said here about signalmen applies in general to gun-pointers and others doing similar work making special demands on the eyesight.

¹⁰ The requirements are $\frac{20}{20}$ in each eye and for gun-pointers $\frac{20}{15}$ in the eye used for sighting.

as lookout, I had a half hour of concentrated misery, since I was absolutely uncertain whether the dancing spots on the horizon were lights to be reported or mere *ignes fatui*. Certainly I was not qualified to be "the eyes of the ship" that night.

2. *Defective Color Vision*.—Obviously a signalman must be free from even slight defects of color perception. It is his business to deal with colors (red, white, and green lights, and various colored flags) seen often in the most unfavorable atmospheric conditions. It is fortunate that our navy like all others recognizes the imperative necessity that every man in it should be free from color defects. It clings, to be sure, to the outworn Holmgren test with wools, when experience has shown that it would be better to use the equally simple and more certain tests of Nagel and of Stilling, as well as the very practical lantern tests. Still our medical officers are very keen in this regard, and it is very rarely the case that any man with color defects slips by them. Moreover, in signal training, the presence of any serious defect would soon show itself by some failure in reading Ardois signals and especially in making out certain flags at signal distance.

3. *Refractive Errors*.—Moderate uncorrected refractive errors—hyperopia and astigmatism of a dioptre or so—are quite compatible with keen sight. Eyes affected with them, however, may give out under prolonged strain either of the eyes themselves or the whole body. This has been seen in the European war, in which, as noted by two English observers, men with only a minimum amount of hyperopia suffer such deterioration of sight from the prolonged strain and fatigue of trench fighting that they become useless as marksmen. In view of the very exacting demands made on a naval signalman, and in view of the fact that in our short-handed navy the hours of work of any one man may be inordinately prolonged, it would seem important that men with even slight errors of refraction should be carefully tested under exacting service conditions, and if they show tendency to give out under the strain, should be kept on probation until it is definitely determined whether they are fit for the work or not.

4. *Defects of the Eye Muscles*.—No man with an obvious squint would be allowed to enter the navy, but many a man may get in with a comparatively large latent deviation caused by muscular im-

balance. These defects cause much the same trouble as refractive errors. That is, they cause undue strain and hence may ultimately produce temporary disability of the eyes as the result of prolonged fatigue of the eyes and the body. It would be well to put candidates for signal work through a careful examination for these errors, and, if they are present, put the candidate himself on probation or in extreme cases reject him altogether for signal work.

Of errors of this sort it may be remarked, first, that confusion due to them is revealed by the fact that it disappears if one eye is shut; second, that troubles of this sort may be accentuated or converted from latent into positive sources of mischief by some of the conditions of naval service, *e. g.*, by the too prolonged use of a spy-glass which excludes one eye from vision.

5. *Slow Reaction Time.*—In the complex process of seeing, interpreting what is seen, and expressing or acting on the interpretation, a certain time is consumed, which differs in different people. In certain avocations it is important that this time be reduced to a minimum. For a railway engineer, a motor driver, a pilot, a gun-pointer, or a signalman this need is imperative. This is well recognized in the navy, where a man, no matter how keen-sighted, how intelligent, or how steady, is rejected for gun-pointing or for signalling, if on trial he is found to be persistently too slow. A man must be sharp in all his reactions, "quick on the trigger," as they say. Such men fortunately are fairly numerous in our navy, containing as it does bright, active, and wholesome youngsters, abounding in physical energy and spirit. Even among these, however, there may be some who do not react quickly enough to be good signalmen. Would it not be well to weed these men out by psychological tests of their reaction time, taken when they are first detached for signal work, rather than, as at present, to find out by weeks of useless trial that they are too slow?

6. *Slow Adaptation.*—A signalman's work on shipboard requires quick adaptation. With varying sunlight, the glare from water and bright work, lights below decks of varying intensities, signal lights, ship's light, and searchlights, he is often required to change suddenly from one condition of illumination to another. This change requires quick retinal adaptation, as otherwise there may be confusion in seeing with a retina ill-adapted to the existing illumination.

It also causes visual discomfort which may after a time result in visual disability. The causes of this discomfort, as Feree has pointed out, are sudden dilatations and contractions of the iris, conjunctival irritation, and fatigue of the exterior eye muscles.

The effect of slow or imperfect adaptation on signalling efficiency has not, so far as I know, been examined scientifically. It would seem as if this were a promising field for the physiologists, psychologists, and our naval medical men.

7. *Effect of After-Images.*—After-images conceivably may be a cause of confusion in signals by night semaphore, by winker light, and by flashlight—and possibly by Ardois. That they have this effect is doubtful, but the case requires study.

8. *Effects of Ocular and General Fatigue.*—It is obvious that to do signal work as it should be done, the signalman must be continuously alert and mentally and physically quick. He must not only be all the time in a state of physical efficiency, but must have a good store of surplus energy so as no time to be close to the limit of his resources. Usually this desirable state obtains, for in the first place our seamen are picked men—physically fit and mentally alert. In the second place, life on board ship is stimulating and wholesome to mind and body, and tends to keep men constantly in good condition.

One serious drawback is to be noted. Reference has been made more than once to the fact that our navy is undermanned. The result is that even in the ordinary routine work the men have to work overtime, and when doing high pressure work, as in performing evolutions or target practice, they may have to work almost continuously for many hours at a time. No body of men, however fit, can keep up continuously under such a strain. Efficiency in all directions is impaired, and, not least, efficiency in signalling.

CONCLUSIONS.

From these desultory observations the following conclusions may be drawn.

1. The standards of vision and color vision now required in the navy should by no means be diminished, but rigorously maintained. It would be well if equally high and rigid standards could be applied to the army. And it becomes us as laymen to uphold in every

way the efforts of the medical men of the navy to maintain these usual standards, which too often are assailed by politicians and well-meaning friends of candidates who, we may believe, are ignorant of the danger to which they would expose our ships.

2. A man detailed for signal work in the navy should be examined for slight errors of refraction and for muscular anomalies. If these are present, he should be tested from time to time to see what effect these errors are having on his signal capacity, and if they are impairing it he should be relegated to other duty.

It would be well to collect a considerable mass of data on this point, so as to determine once for all the effect that by and large these errors of refraction do produce on signalling ability and other tasks—gun-pointing and lookout work—which require a high degree of sustained visual power.

3. It would be well if psychological tests of the reaction time could be made to determine the fitness of men for signal work, and, particularly when the tests indicated sluggishness, to repeat them later from time to time as checks on the signalling efficiency.

From these experiments, too, a good deal of valuable data could in time be accumulated, which would, *e. g.*, show the true relation existing between reaction-time tests and signalling efficiency.

4. The present deplorable undermanning of the navy should not be permitted to continue. Putting it on no higher plane than simple business prudence and national self-interest, it is vital that the highly specialized work of our navy should be properly done; and it cannot be done when a ship, as now, carries but two thirds of its minimum complement.

In conclusion, I should like to put in a plea for the extension of signalling throughout the country. It is healthful stimulating work, that carries one into the open, that becomes fairly fascinating as one pursues it, and that may be extremely valuable in time of need. To be able to talk to a companion or stranger miles away by the motions of the wig-wag or hand semaphore (made with a handkerchief and stick), by sound signals, or by extemporized flash lantern or searchlight not only is often a great saving of time and trouble, but in many an instance will be the means of averting some supreme disaster and of saving life itself.

SOME PROPERTIES OF VIBRATING TELEPHONE DIAPHRAGMS.

By A. E. KENNELLY, S.D., A.M., AND H. O. TAYLOR, PH.D.

(Read April 14, 1916.)

This investigation was conducted by the Research Division of the Electrical Engineering Department, of the Massachusetts Institute of Technology, during the years 1915-16, under an appropriation from the American Telephone and Telegraph Company. The experimental work was carried on at Pierce Hall, Harvard University. It constitutes a continuation of the researches reported by the same authors in the paper read last year before the American Philosophical Society,¹ and in the paper by Kennelly and Affel, read last year before the American Academy of Arts and Sciences,² dealing with the motional-impedance circle of telephone receivers.

It is now well established that the motional-impedance circle of a telephone receiver; *i. e.*, the circular locus of that part of a receiver's impedance which is due to the motion of the diaphragm, enables the characteristic constants A , m , r and s of the instrument to be determined experimentally. Its diameter, OD , Fig. 4, is depressed below the resistance axis OA (resistance component of impedance), through a certain angle, AOD , which is designated by $\beta_1^\circ + \beta_2^\circ$. Here β_1° is regarded as the angle of lag of the pull on the diaphragm behind the alternating current in the coils giving rise thereto; while β_2° is regarded as the angle of lag of the E.M.F. induced in the coils, behind the velocity of the diaphragm's vibrational motion producing it.

The researches here reported have been two-fold namely:

¹ "Explorations over the Vibrating Surfaces of Telephonic Diaphragms under Simple, Impressed Tones," by A. E. Kennelly and H. O. Taylor, *Proc. Am. Philos. Soc.*, Vol. LIV., April 22, 1915.

² Bibliography, 10.

1. Investigations were made with a view to ascertaining how the two lag angles, β_1° and β_2° compared with each other, in a given receiver, and to what extent they depended upon the impressed frequency and upon variations in construction.

2. In the course of this research, which has involved the observation and plotting of some sixty motional-impedance circles, certain departures from the circle were noted, due to abnormalities or irregularities in the mechanics of the receiver diaphragm under test. Investigation was directed towards determining the nature and causes of these departures.

1. INVESTIGATION OF THE DEPRESSION ANGLES β_1° AND β_2° .

The method adopted for investigating the magnitudes of the two component depression angles β_1° and β_2° was an optical one, involving Lissajous figures.³ A small and powerful beam of light

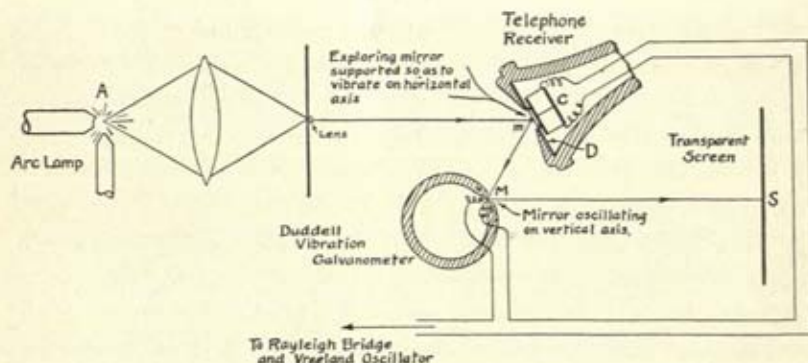


FIG. 1. Diagram of Optical System for Producing Lissajous' Figures.

from an arc lamp, *A*, Fig. 1, was directed onto a tiny triangular exploring mirror, about 0.5 mm. in length of edge *m*, as referred to in both of the preceding papers of this research.⁴ This mirror was elastically supported in contact with the center of the outer surface of the telephone diaphragm *D*, so that vibratory displacements of the latter would cause the mirror, *m*, to rock about a horizontal

³ Bibliography, 1.

⁴ Bibliography, 9 and 10.

axis. The reflected arc-light beam then fell upon the mirror M , of a Duddell bifilar vibration galvanometer,⁵ in the same circuit as the telephone receiver coils C , and so arranged as to vibrate about a vertical axis, under the action of the current which actuated the telephone. The beam finally produced a spot of light on the transparent screen, S . Owing to the two independent mirror vibrations being of the same frequency, but about mutually perpendicular axes, this spot of light traced Lissajous figures on the screen, and the observed shape of these figures enabled calculations to be made as to the phase differences between the movements of the two mirrors m and M . It was therefore necessary to make an initial examination into the phase relations of the Duddell galvanometer mirror M , with respect to the alternating current operating it.

Observations on the phase relations of vibration galvanometer mirrors have already been published.⁶ It was found, however, in the research here reported, that as might be expected from the differential equation of motion of such an instrument as an oscillograph or vibration galvanometer, it inherently possesses a motional-impedance circle, like a telephone receiver. The motional-impedance circle of a vibration galvanometer, or an oscillograph, differs from that of the ordinary telephone receiver, in having its diameter coincident with the resistance axis, or very nearly so; so that $\beta_1^0 = \beta_2^0 = 0$. This means that the vibrational angular velocity at resonance is in phase with the vibromotive force, which in this case is also in phase with the actuating alternating current. From an observation of the instrument's motional-impedance circle and deflections, the essential mechanical and electrical constants of the instrument, for its particular state of adjustment, can be readily determined. This theory and technique for vibration instruments, which are only side issues of the main research here reported, are discussed in Appendix I. It suffices here to note that provided the Duddell galvanometer is out of tune, even only a few per cent. with respect to the actuating currents, its mirror displacements will be substantially either in phase with, or in opposite phase to, the ac-

⁵ Bibliography, 5.

⁶ Bibliography, 6.

tuating current. If the alternating current has a lower frequency than the particular resonant frequency to which the instrument is adjusted, the mirror displacements will be substantially in phase with the current; whereas if the A.C. frequency is higher than the

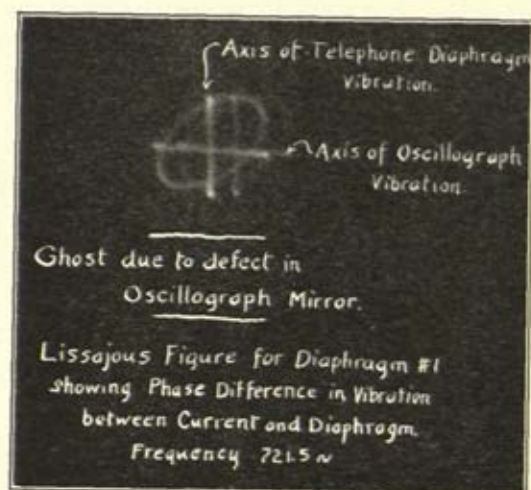


FIG. 2.

instrument's resonant frequency, the mirror displacements will be in opposite phase to the current. There was therefore no practical difficulty in ensuring one or the other of these two conditions, as might be desired, for impressed alternating-current frequencies up to 1,500 \sim , the Duddell galvanometer employed having a range from 100 to 2,000 \sim .

Fig. 2 is a photographic record of a Lissajous figure, obtained on the screen *S* of Fig. 1, for a particular case. These test records were photographed and analyzed. The well-known analysis is reproduced in Fig. 3. The Lissajous ellipse *ABCD* about the center *o* and coördinate axes *Xx* and *Yy*, is supposed to be described in the direction of the arrows. Corresponding points on the circles *A₁B₁C₁D₁* and *A₂B₂C₂D₂*, are projections from the ellipse on the *Y* and *X* axes respectively. The phase difference between the simple harmonic motions of *Yy* and *Xx* is any one of the four equal angles α_1 , α_2 , α_3 , and α_4 . Owing to imperfections in the photographic

record and tracing process, these four angles ordinarily are not quite equal; but their arithmetical mean may be taken as the observed phase difference. Since in the photographic record, the oscillations

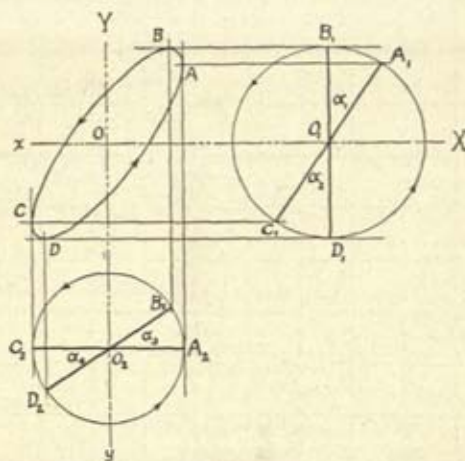


FIG. 3. Lissajous' Diagram.

of the telephone diaphragm produce the vertical component, and the oscillations of the galvanometer mirror (in phase with the current), produce the horizontal component, the lag of the diaphragm vibration behind the current becomes determined. This lag angle should agree with the lag computed by mechanical impedance ($90^\circ - \alpha^\circ$), except for the angle β_1° . It was found that by varying the impressed A. C. frequency, the Lissajous ellipse could be made to pass through all its forms, *i. e.*, straight line, ellipse, circle, ellipse and straight line. The particular form offering easiest recognition and greatest precision of measurement, is the straight line, under which condition the two displacements are in either cophase or opposition. This means that the diaphragm displacement would be in \pm cophase with the current, or the diaphragm velocity in quadrature with the current. Referring to Fig. 4, OA represents the standard phase of A. C. vector current. OB , in quadrature therewith, is the phase of the diaphragm's vibrational velocity when the Lissajous figure is a straight line. By observing, on the Rayleigh

bridge, the motional impedance OC of the telephone at this frequency, the angle BOC is the lag of the motional E. M. F. behind the velocity producing it, and is equal to the angle β_2^0 . Since the

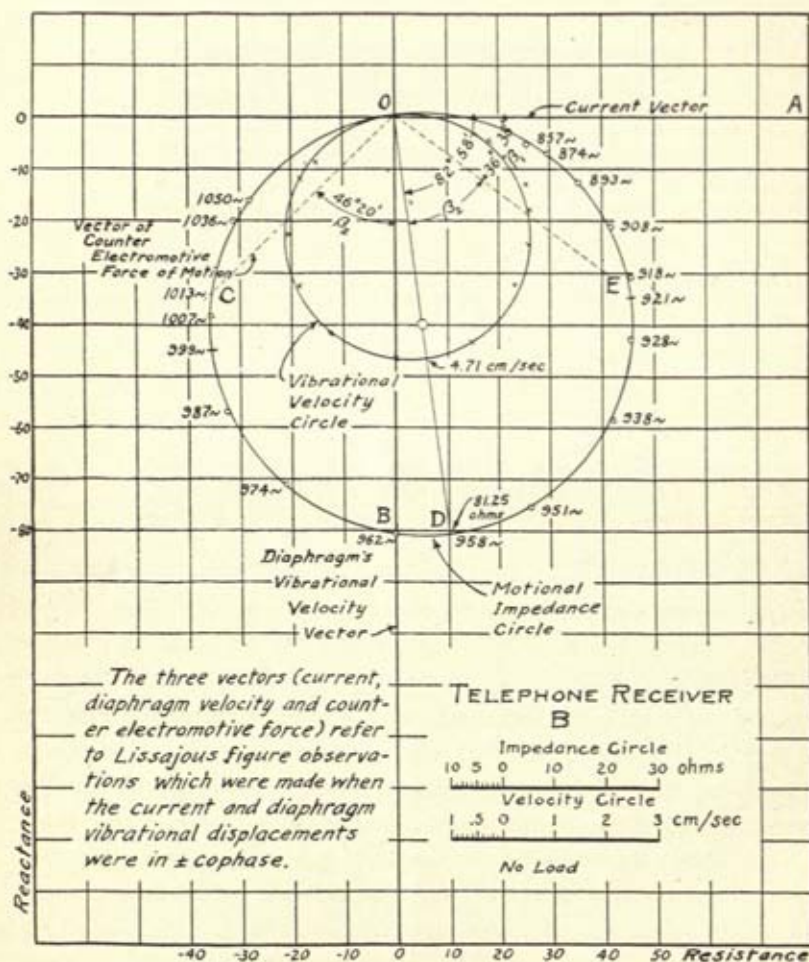


FIG. 4. Undistorted Circles of Motional-Impedance and Velocity.

depression angle AOD of the motional impedance circle, taken from the observation plot is $\beta_1^0 + \beta_2^0$, the angle β_1^0 is immediately determined. The test therefore requires the motional-impedance circle to be obtained over the principal range of frequencies, in Fig. 4 from

857 ~ to 1,050 ~, then adjusting the frequency to the particular value (1,013 ~) at which the Lissajous figure becomes a straight line, measuring the motional impedance in the circle at this point, and then deducing β_2° and β_1° geometrically. In the case of Fig. 4, $\beta_1^\circ = 36^\circ 38'$ and $\beta_2^\circ = 46^\circ 20'$. The precision obtained in measuring these angles corresponds however to a probable error of one degree for a single observation, so that reliance cannot be placed on the minutes of arc.

The following table collects the results obtained with one bipolar telephone⁷ receiver *B* with two successive diaphragms, *i. e.*, dia-

TABLE I.
EFFECT OF DIMINISHING RESONANT FREQUENCY ON β_1° AND β_2° .

Test No.	Tel. Diaph.	Load Gm.	Z_m Ohms.	f_0 m.	Δ hyps sec.	A dynes absamp. 10^6 .	m Gm.	r dynes kine.	s dynes cm. 10^6 .	β_1 .	β_2 .	At/f' m.	$\beta_1 + \beta_2$.
1	<i>B</i>	0	81.25	958	245	5.49	0.757	371	25.75	$36^\circ 38'$	$46^\circ 20'$	1,013	$82^\circ 58'$
2	<i>B</i>	0.6	97.5	761.4	169	7.75	1.32	616	41.5	$29^\circ 52'$	$46^\circ 56'$	811	$76^\circ 48'$
3	<i>B</i>	0.6	97.5	796.5	173	6.69	1.33	459	33.3	$25^\circ 17'$	$53^\circ 09'$	850	$78^\circ 26'$
4	<i>B</i>	0.73	92.5	794.5	141	7.18	1.95	551	48.6	$24^\circ 54'$	$51^\circ 42'$	845	$76^\circ 36'$
5	<i>B</i>	1.2	102.5	680	100	7.07	2.44	487	44.6	$19^\circ 53'$	$52^\circ 17'$	732	$72^\circ 10'$
6	1	0	17.6	1,100	261	5.36	3.08	1,608	148	$57^\circ 44'$	$28^\circ 54'$	1,132	$86^\circ 38'$

Note: In the case of Test 2, the load of 0.6 gm. was applied to the diaphragm at its center; whereas in the case of Test 3 it was applied at a point 1 cm. off the center.

phragm *B* and diaphragm 1. The first line in the table corresponds to the set of observations given in Fig. 4, where there was no load attached to the center of the diaphragm, the diameter Z_m of the motional-impedance circle was 81.25 ohms, the resonant frequency f_0 was 958 ~, the damping coefficient Δ , 245 hyperbolic radians per second, the force constant A , 5.49 megadynes per absampere, the equivalent mass m , 0.757 gm., the frictional or mechanical resistance r , 371 dynes per kine, the elastic constant s , 25.75 megadynes per cm. At the frequency f' , of 1,013 ~, the angle β_2° was $46^\circ 20'$, and at 958 ~, β_1° was inferred to be $36^\circ 38'$.

The successive series of observations 2, 4, and 5 were obtained by attaching increasing loads to the diaphragm, so as to lower the

⁷ The details of this receiver are given in the paper of bibliography No. 10.

resonant frequency f_0 . In the case of test No. 3, the load, a small copper disk, about 1 cm. in diameter, was intentionally placed on the diaphragm excentrically, *i. e.*, at a distance of 1 cm. off center. It will be seen from the table that as the resonant frequency f_0 was lowered, and with it f' , the magnitude of β_1° was considerably reduced but β_2° was, if anything, slightly increased. The sum $\beta_1^\circ + \beta_2^\circ$ between $f_0 = 680 \sim$ and $f_0 = 958 \sim$ has increased from about 72° to 83° ; while β_1° has increased from 20° to 37° .

The inference to be drawn from this series of tests is that β_1° and β_2° are, in general, unequal. The angle β_1° increases with the frequency, but β_2° is apparently more nearly constant. A reason which suggests itself for this relation is that the lag β_1° , between flux and current, is due not only to hysteresis but also to the eddy currents of skin effect. Owing to hysteresis and skin effect in the steel cores of the telephone electromagnet, the resultant flux lags behind the exciting current to an extent β_1° which depends upon the impressed frequency and may rise theoretically to 45° at relatively high frequencies, owing to skin effect alone. In the case of β_2° , however, this is a lag between vibrational velocity of the diaphragm and the C.E.M.F. thereby produced. An oscillatory change in length of air-gap may set up hysteretic and eddy-current retardation in the flux oscillation thereby generated, but the skin effect should perhaps be less than when the flux oscillation is generated from an external magnetizing coil.

In order to ascertain the effect of an increased air-gap on the angles β_1° and β_2° , ring washers of pasteboard, of successively increasing thickness, were inserted under the diaphragm, between it and the clamping surface of the receiver. Starting with a clearance between poles and diaphragm, of 0.32 mm. this was increased up to about 1 mm. with the results as shown in the following table, the

TABLE II.
EFFECT OF INCREASING AIR-GAP ON β_1 AND β_2 .

Test No.	Tel. Diaph.	Clearance Mm.	D Ohms.	f_0 ω .	Δ hypos. sec.	$\frac{A}{\text{absamp.}} \times 10^6$.	m Gm.	$\frac{r}{\text{kine.}}$ dynes	$\frac{s}{\text{cm.}} \times 10^6$.	β_1° .	β_2° .	$At f'$ ω .	$\beta_1^\circ + \beta_2^\circ$.
1	B	0.32	92.5	794.5	141	7.18	1.95	551	48.6	$24^\circ 54'$	$51^\circ 42'$	845	$76^\circ 36'$
2	B	0.70	25.6	764.3	76.4	3.92	3.93	600	90.6	$36^\circ 0'$	$48^\circ 42'$	783	$84^\circ 42'$
3	B	1.08	9.9	770.6	61.9	2.14	3.76	465	88.5	$32^\circ 54'$	$50^\circ 24'$	791	$83^\circ 18'$

load attached to the center of the diaphragm being 0.73 gm. in each case.

It appears from this table that the increase in air-gap greatly diminished the force-factor A and the amplitude of vibration, which is proportional to the diameter D of the impedance circle. The equivalent mass and the elastic constant are both increased. It appears that β_2° has undergone but little change; whereas β_1° has distinctly increased.

The inference to be drawn from Table I. and Table II. collectively, is that β_2° seems to be nearly constant for a given receiver; but that β_1° is affected both by the air-gap length and the impressed frequency. Thus there seems to be no close connection between β_1° and β_2° . In the first five cases of Table I., and in all the cases of Table II., the angle β_2° exceeds β_1° ; but this is not necessarily true in all cases. In test 6 of Table I., β_2° is considerably less than β_1° . This case refers to another receiver and diaphragm. In the particular instrument investigated by Kennelly and Pierce⁸ in 1912, the angles β_1° and β_2° happened to be nearly equal.

A number of tests were made with a series of different thicknesses of diaphragm in one and the same receiver. The results showed that the angles β_1° and β_2° were different with different diaphragms; but the quantitative relations have not yet been ascertained.

2. INVESTIGATION OF REËNTRANT AND DISTORTED CIRCLE DIAGRAMS.

The engineering research department of the Western Electric Co., when examining some motional-impedance diagrams in 1913, seem first to have discovered cases of distorted and reëntrant circles. Such cases presented themselves in the course of the M. I. T. researches in 1915. Distorted diagrams of this type appear in Figs. 5 to 9 and 11 to 17 of this paper.

These distorted circle diagrams presented themselves at first in a small percentage of the cases of telephone receivers tested in the M. I. T. researches. When first encountered in these, they were regarded as curiosities of unknown origin, and were set aside. At

⁸ Bibliography, 7.

a later period, they were taken up for investigation, since marked abnormalities of such a type adversely affect the circle-diagram method of analyzing telephone receivers. For a long time, the

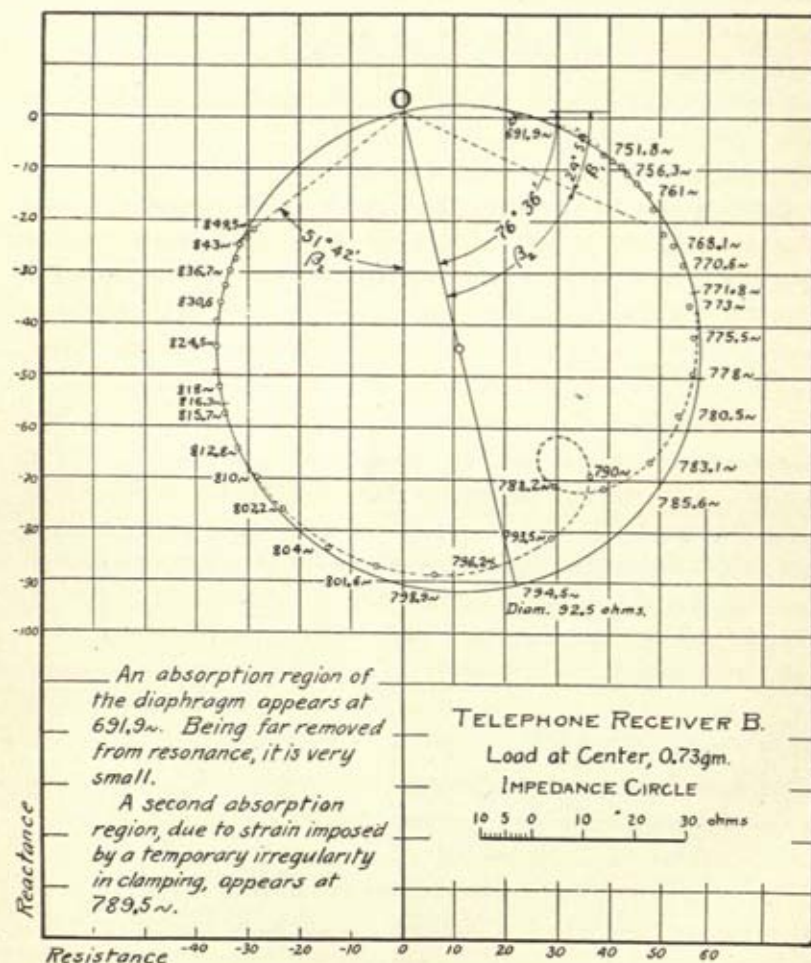


FIG. 5. Distorted Motional-Impedance Circle. Small Distortion, Rising on the right.

cause of these abnormalities baffled enquiry; but finally their origin was apparently brought to light, and it also became possible to produce them artificially, at will.

Fig. 4, already referred to in connection with the depression angles β_1° and β_2° , presents a smooth motional-impedance circle, all the observed points falling nicely upon its circumference. Nevertheless, there is reason to believe that this circle contains a small inner loop distortion between the origin o and the lowest indicated frequency of $857 \sim$. No measurements were made in this case below $857 \sim$; but it is probable that, had they been made, the distortion loop would have been too small to notice. The central amplitudes of vibration were also measured by the explorer in the case of Fig. 4, and from these the vibrational velocities x of the diaphragm were computed. They lie closely to the inner circle indicated in the figure. This shows, moreover, as has been pointed out in earlier publications, that the motional-impedance circle may be regarded as a velocity circle, taken to a suitable scale, disregarding the phase lag β_2° .

When the diaphragm of the receiver B , considered in Fig. 4, was loaded at the center by a small copper washer, about 1 cm. in diameter and weighing 0.73 gm., a repetition of the test gave the diagram shown in Fig. 5, the analysis of which appears in Table I. This diagram shows two internal loops or abnormalities, one a little loop near $691.9 \sim$, well defined however by numerous observations, and the other a larger loop near $789.5 \sim$. The latter proved to be a temporary visitor, and since it did not appear in subsequent tests, it may be left out of consideration here. It suffices, therefore, to notice that the loop at $691.9 \sim$ had a length of about 2.5 ohms, and occurs in the circle at an angular distance of about 30° from o , the origin of the circle. The resonant frequency of the loaded diaphragm as a whole was apparently $794.5 \sim$.

The load on the diaphragm was then increased to a total of 0.975 gm. This had the effect of bringing the resonant frequency down to $699.4 \sim$; or close to the frequency at which the abnormality (at $691.9 \sim$) had appeared. The result of the test under this condition is shown in Fig. 6. The distortion loop is central at $697.2 \sim$, and has a length of 42.5 ohms on the motional-impedance scale. It is evident that when the diaphragm is brought nearly into resonance with the frequency of the distortion loop, the magnitude of the

that, at least to a first approximation, the distortion consisted of a negative or absorption circle, of the same general character as the main impedance circle, but which is swept over much more rapidly. The constants A' , m' , r' and s' of this absorption circle were capable of being roughly determined.

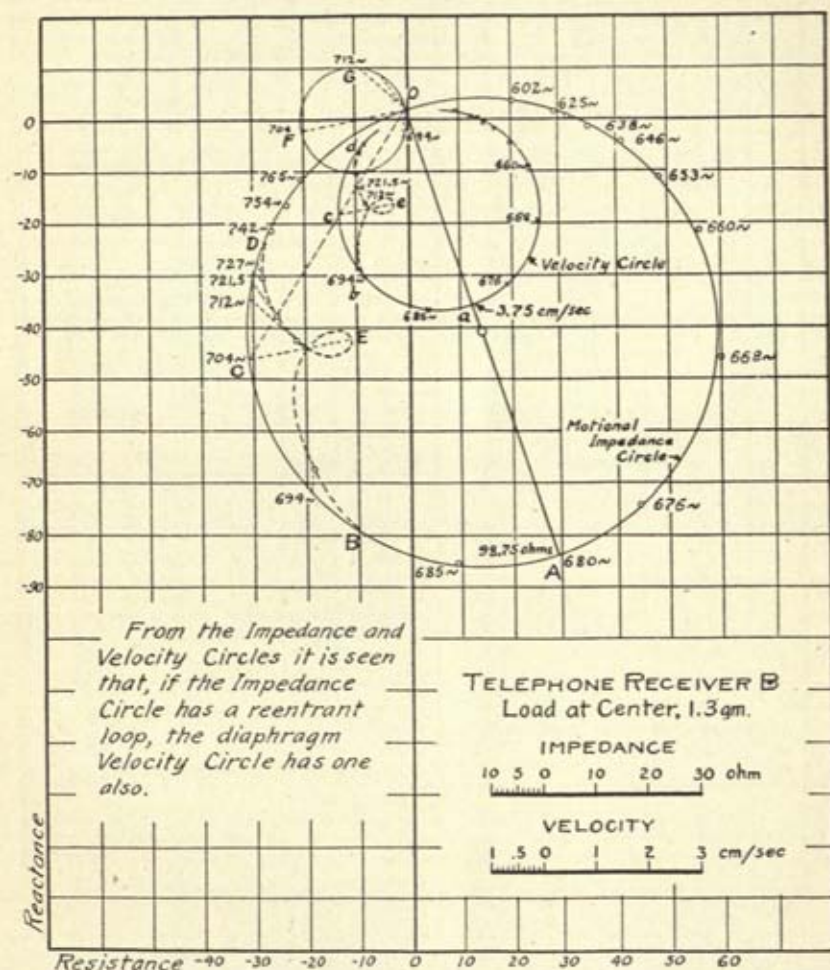


FIG. 7. Distorted Impedance and Velocity Circles. Distortion Loop Setting in the Left.

By still further increasing the load on the diaphragm to 1.3 gm., and thus bringing its resonant frequency to 680~, or below

the frequency of the distortion, the next test, indicated in Fig. 7, showed that the distortion loop, central at $704\sim$, had moved over to the left hand side of the diameter OA , and had diminished to

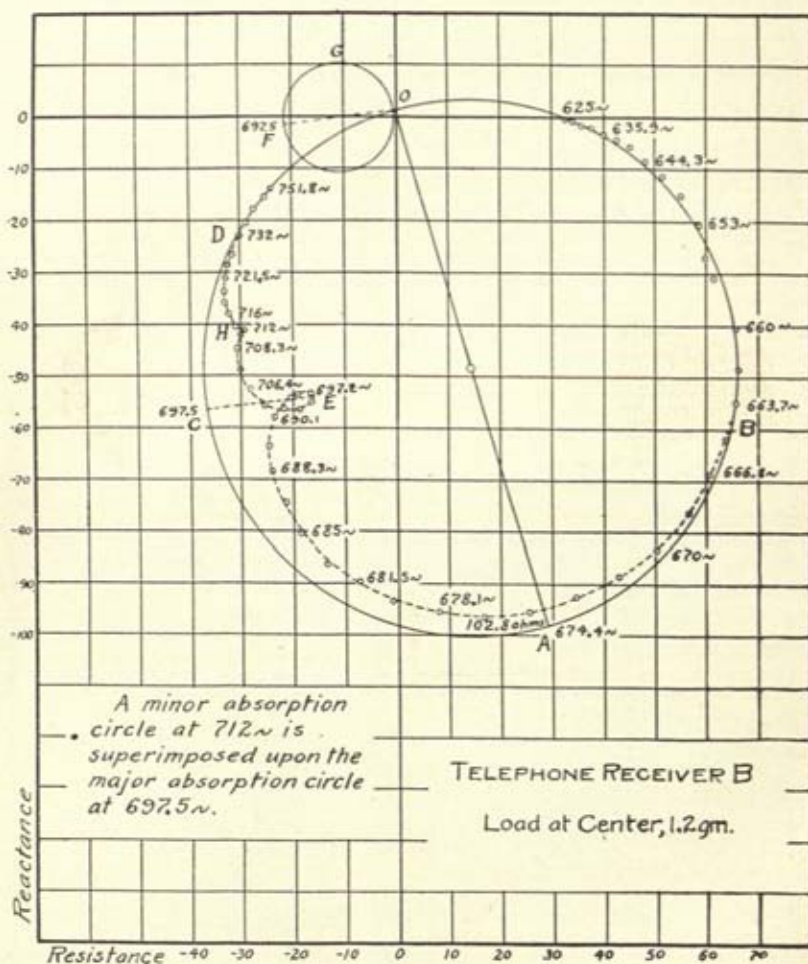


FIG. 8. Doubly Distorted Motional-Impedance Circle.

about 17 ohms. of departure CE , from the main circle. The central amplitudes of the diaphragm's vibration were again measured in this case, and from them the inner circle of vibrational velocity $Oabcd$ was deduced. This also shows the distortion at e . The cor-

responding approximate motional-impedance distortion circle is marked at OGF , at an angle lagging more than 90° behind the diameter OA .

On reducing the diaphragm load to 1.2 gm., the distortion loop in Fig. 8 was enlarged to 20.5 ohms at CE ; and the distortion at $697.5 \sim$ is brought slightly nearer to the bottom of the circle. The deduced distortion circle OGF , is also brought to a lag of somewhat more than 90° behind the diameter OA . Incidentally a small new and transient distortion appears at H .

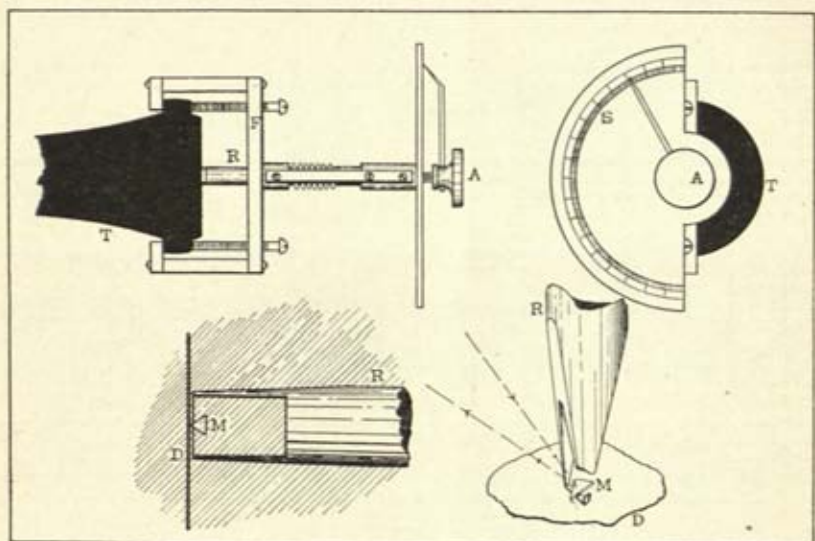


FIG. 9. Amplitude Measurer.

Summing up the disclosures of the last few figures, it appears that one and the same distortional disturbance in a diaphragm, resident near $700 \sim$, by suitably diminishing the resonant frequency of the diaphragm in successive steps, was made to appear, first as a small loop near the origin on the right-hand side, then as a greatly magnified loop near the diameter, and finally passing off as a small loop near the origin on the left-hand side. The deviations from the main circle are only approximately represented by absorption circles. Moreover, the angle COF , Fig. 7, is approximately equal to the angle COA .

An outline theory of the absorption graph is offered in Appendix II.

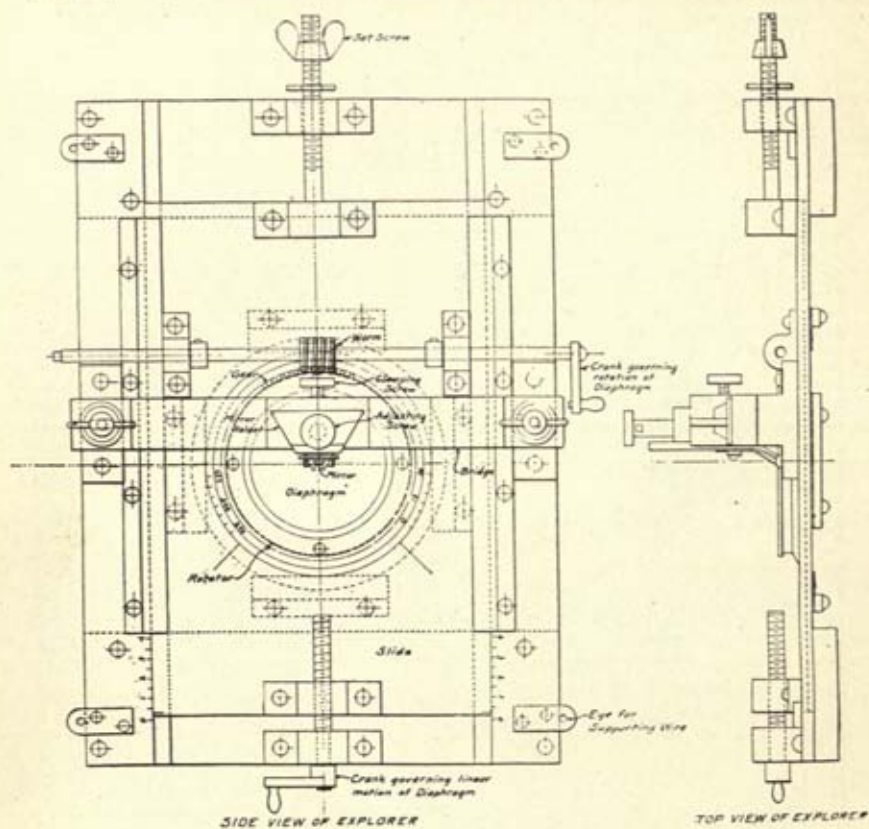


FIG. 10.

It was noticed, after a time, that whenever the distortion near $700 \sim$ manifested itself, the amplitude measurer of Fig. 9 was mounted on the receiver. This particular form of amplitude measurer was described in an earlier publication. This led to the suspicion that the clamping screws in the brass frame *F* might be responsible for these distortions of the impedance circle. On actual trial, the removal of the amplitude measurer and its clamping frame

from the receiver, removed the distortion from the impedance circle. It thus became evident that the application of clamping pressure to the composition cap of the telephone receiver, warped it slightly, and

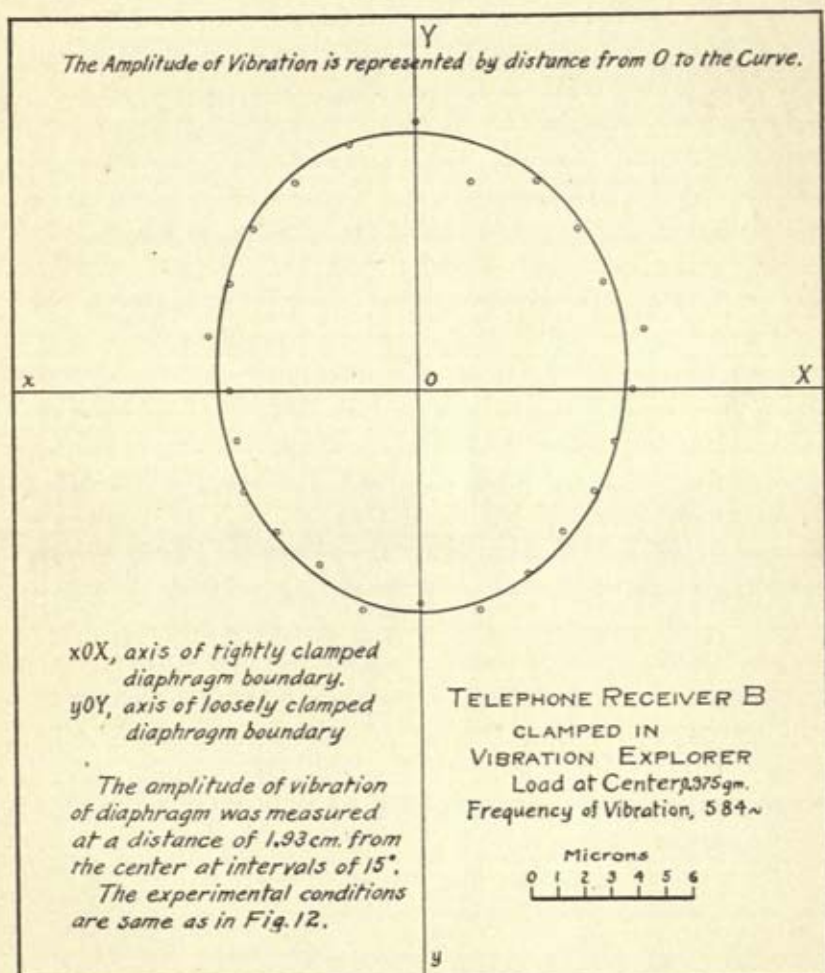


FIG. 11. Amplitudes of Vibration around Imperfectly Clamped Diaphragm.

interfered with the uniformity of boundary vibration around the clamping circle. This also indicated the importance of employing metallic clamping rings around the cap, or otherwise ensuring that

⁹ Bibliography, Kennelly and Affel, Fig. 10.

the clamping of the diaphragm is unchanged when the amplitude measurer is applied.

In order to investigate the matter further, the diaphragm *B* of the receiver was mounted in the vibration explorer Fig. 10, described in a preceding paper.¹⁰ It may be seen that the diaphragm is here supported under a clamping ring, which is attached to the main frame by four machine screws. Two of these screws, diametrically opposite each other, were removed, leaving the diaphragm clamped tightly under opposite points only, thus simulating the effects of the clamps of the amplitude explorer in Fig. 9. The diaphragm had a central load of 0.975 gm., and the same receiver *B* was screwed into the explorer to actuate it. The impressed frequency was maintained at 584 ~, and with an alternating-current strength of 2.26 milliamperes rms. The amplitude of vibration under these conditions was measured at various angular positions 15° apart, at uniform radial distances, 1.93 cm. from the center, the clamping-ring diameter being 5.24 cm. The results obtained are shown geometrically in Fig. 11. Here the axis of the tightly clamped boundary is horizontal, and the axis of the loosely clamped boundary where the screws were removed, is vertical. It will be observed that the average amplitude in the latter axis is about 9 microns; while in the former it is about 7.6 microns; so that the mean amplitude along the loosely clamped diameter is some 18 per cent. more than that along the tightly clamped diameter, with intermediate values in intermediate directions. This indicates the importance of securing uniformly tight clamping around the boundary of a telephone diaphragm.

The motional-impedance diagram for this case is shown in Fig. 12. No localized distortion loop is visible; but there is a general shrinking of impedance, and therefore of diaphragm velocity, over a considerable range of the diagram (559 ~ to 618 ~). No distortion loop was obtained at any time in the vibration-explorer tests, as though no definite absorption frequency was brought about; but there was a fairly proportional degree of absorption over a wide range of impressed frequency.

¹⁰ Bibliography No. 9, Kennelly and Taylor.

The inference from the preceding results was that a distortion loop was due to the presence of local and loosely clamped diaphragm boundary areas, having a natural frequency independent of the main

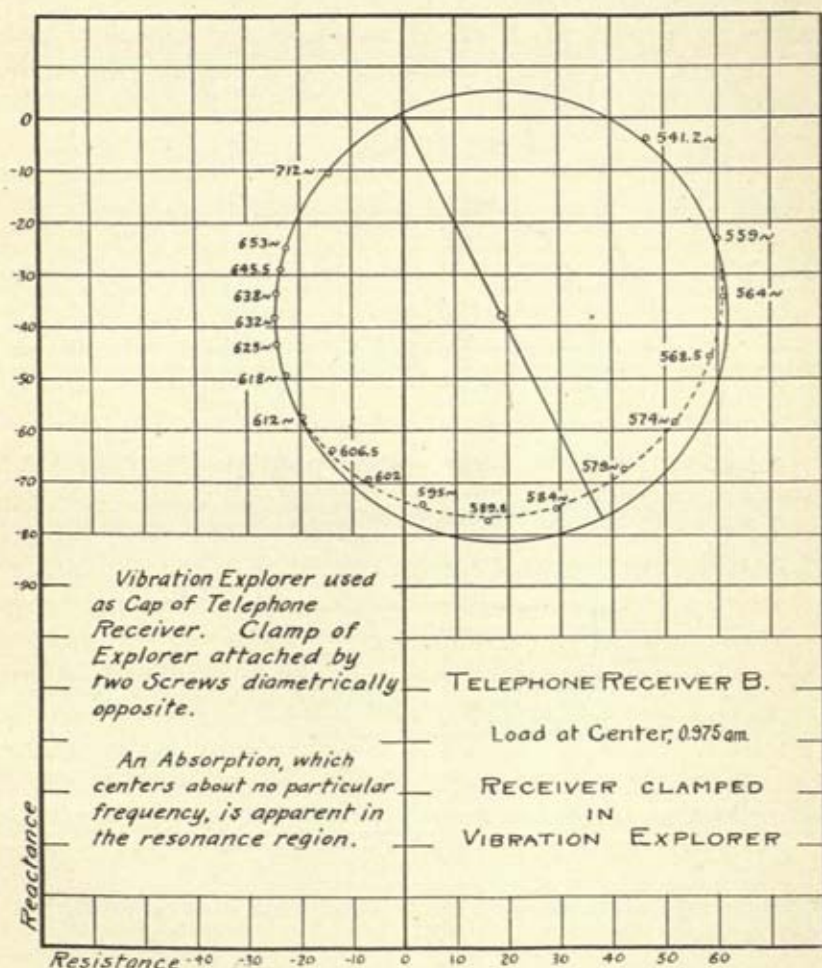


FIG. 12. Distorted Impedance Circle with Unlocalized Distortion.

diaphragm, and having constants r , m , and s of their own. The local areas received their vibrational energy from the main diaphragm. According to this view, it would only be necessary to attach a local vibrational system, with its own r , m , and s to a prop-

erly clamped diaphragm, in order to simulate the localized distortional behavior of an irregularly clamped diaphragm.

With this object in view, a small piece of bent hard copper strip was fastened by sealing wax to the center of the diaphragm, as shown in Fig. 13. The weight of this spring was 0.6 gm. in all, of which the free portion weighed only 0.2 gm. The free period

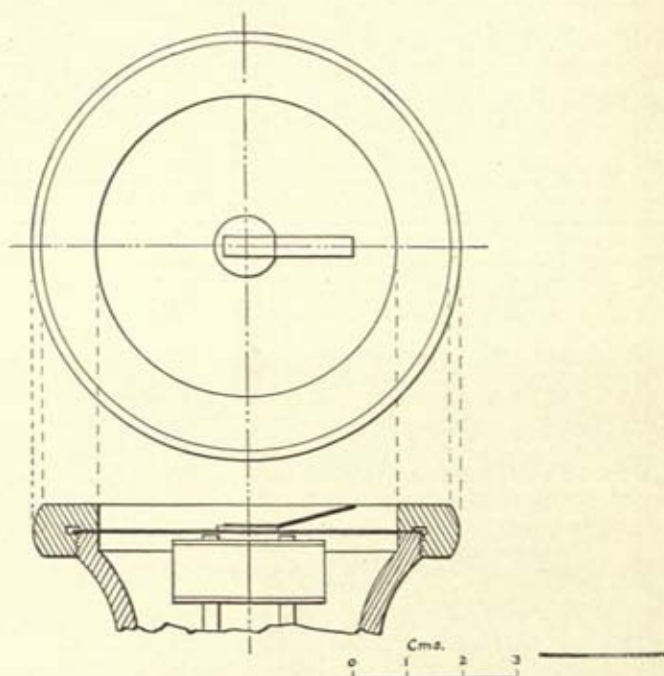


FIG. 13. Plan and Longitudinal Section of the Test Receiver with Secondary Vibrational System Attached to Center of Diaphragm.

of this spring, when mounted on the diaphragm, was adjusted, by trial, to approximately $750\sim$, which is nearly the same as the diaphragm thus loaded. Fig. 14 shows the motional-impedance diagram of receiver *B* with the diaphragm and its spring load. It will be observed that between $660\sim$ and $866\sim$, the diagram forms a large reëntrant loop, and the actual amplitude, at $753\sim$, is only about 4 per cent. of the inferred undistorted diameter *OA*. It is evident that, in this case, the form of the diagram is completely

changed, there being now two maximum motional-impedances, one near $676\sim$, and the other near $840\sim$. Nearly midway between them ($753\sim$), the motional impedance almost vanishes at OB .

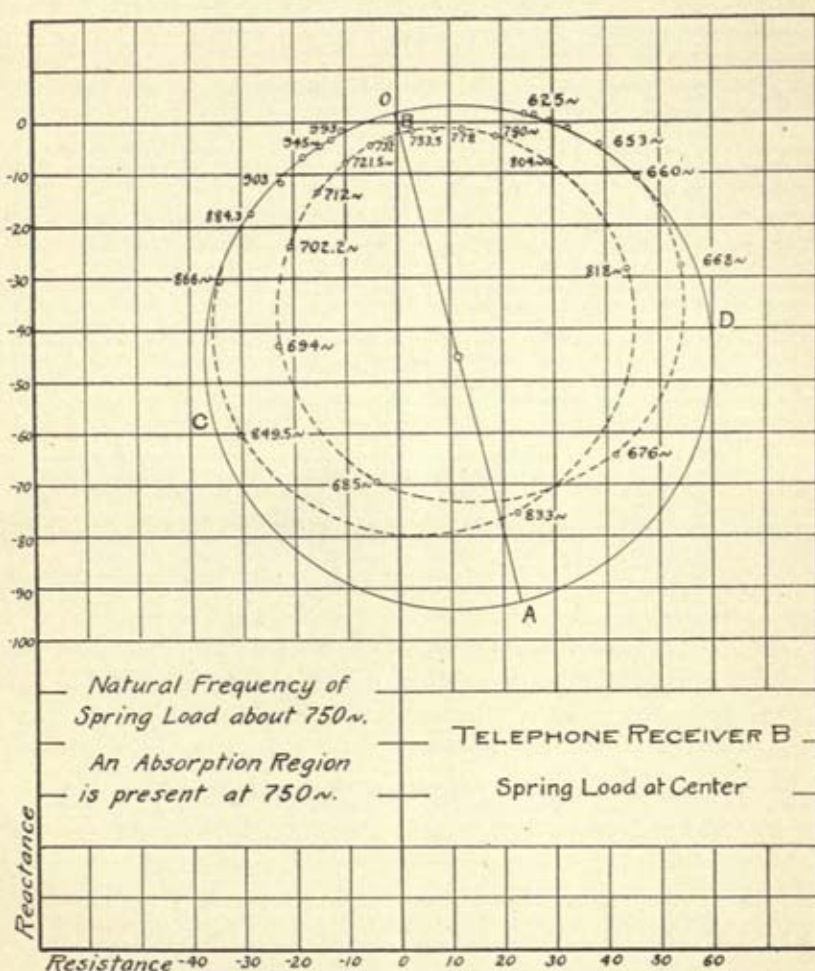


FIG. 14. Distorted Motional-Impedance Diagram. Large Distortion Loop.

The amplitudes of vibration of the diaphragm, as deduced from the motional-impedance diagram of Fig. 14, are shown in Fig. 15 with amplitude ordinates, and abscissas in impressed frequency. It will be seen that the amplitude almost vanishes at $753\sim$, which is

approximately the natural frequency of the loaded diaphragm obtained from the undistorted circle *OCAD* of Fig. 14. The curve of Fig. 15 has two sharp resonance peaks, whereas the inferred amplitude curve of the diaphragm, without abnormality, has, as usual, only one, *ABCDE*. It was noticed during the test represented in

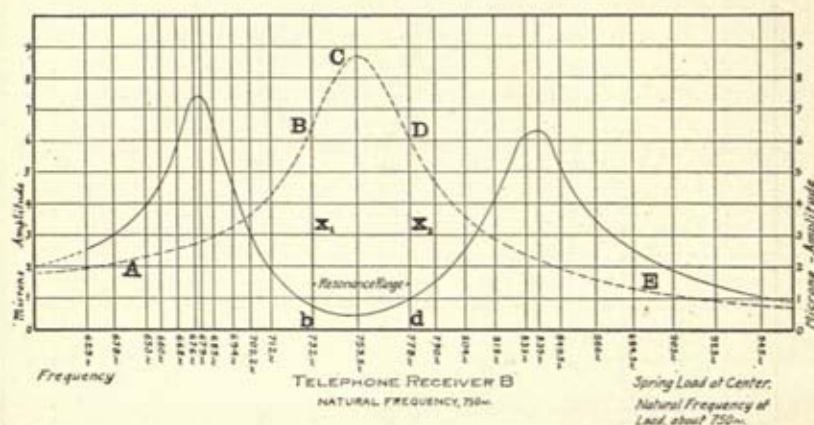


FIG. 15. Relative Amplitudes of Diaphragm Vibration with Spring Attached.

Fig. 14, that the receiver gave practically no sound at 753~; but gave loud sounds for frequencies slightly removed on either side of this. This peculiar property of a spring-loaded diaphragm to be silent at a certain selected frequency, but to sound loudly at a small departure therefrom on either side, may have practical applications.

The natural frequency of the spring load was then altered to about 913~, leaving the natural frequency of the diaphragm at 712~, a little below its preceding value. The effect of this change on the motional-impedance diagram is shown in Fig. 16. Here the distortion loop is reduced in diameter nearly one half, and is located much nearer to the origin on the left-hand side of the impedance circle.

By lowering slightly the natural frequency of the diaphragm to about 698~, leaving the natural frequency of the spring load unaltered, the distortion loop in Fig. 17 is brought still nearer to the origin *O*, and its dimensions further diminished.

When two independently clamped telephone diaphragms were mounted, one below the other, in parallel planes, the upper supported in the vibration explorer, the lower in the receiver *B*, and

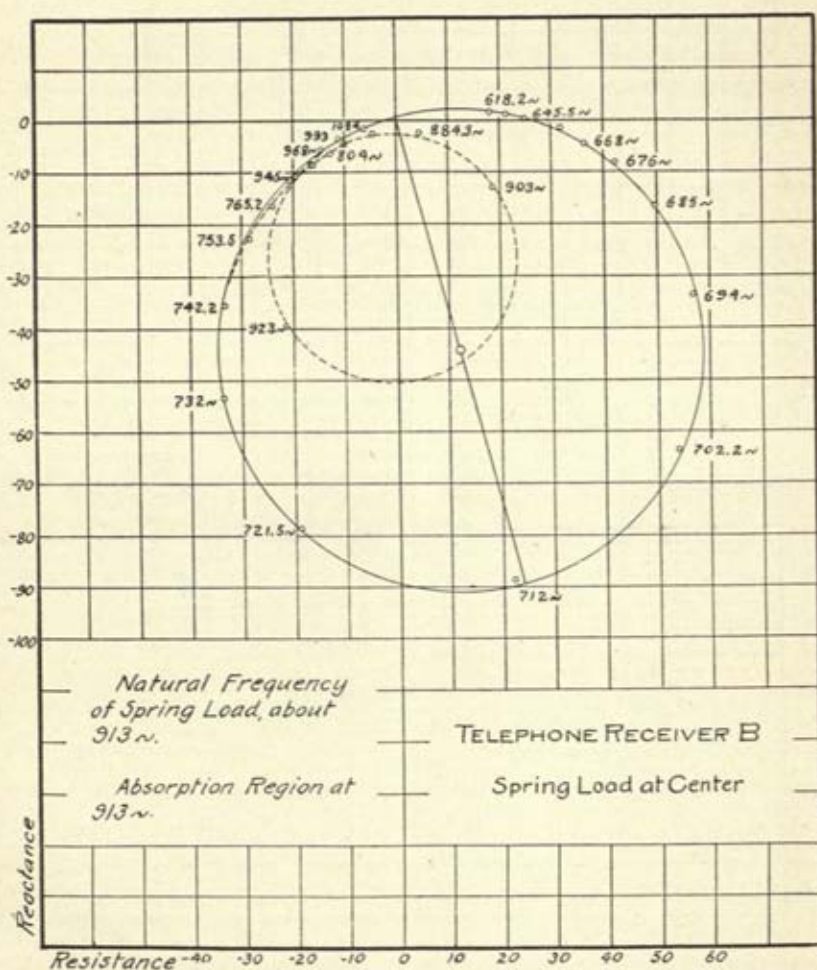


FIG. 16. Distorted Impedance Circle. Spring Load out of Tune with Diaphragm.

both connected rigidly, between their centers, by an aluminum bar 6 cm. long, and 2 mm. \times 2 mm. in section, the whole system gave an undistorted motional-impedance circle, corresponding to the nat-

ural frequency and other constants of the composite single system. The inference seems therefore to be warranted, that any vibratory

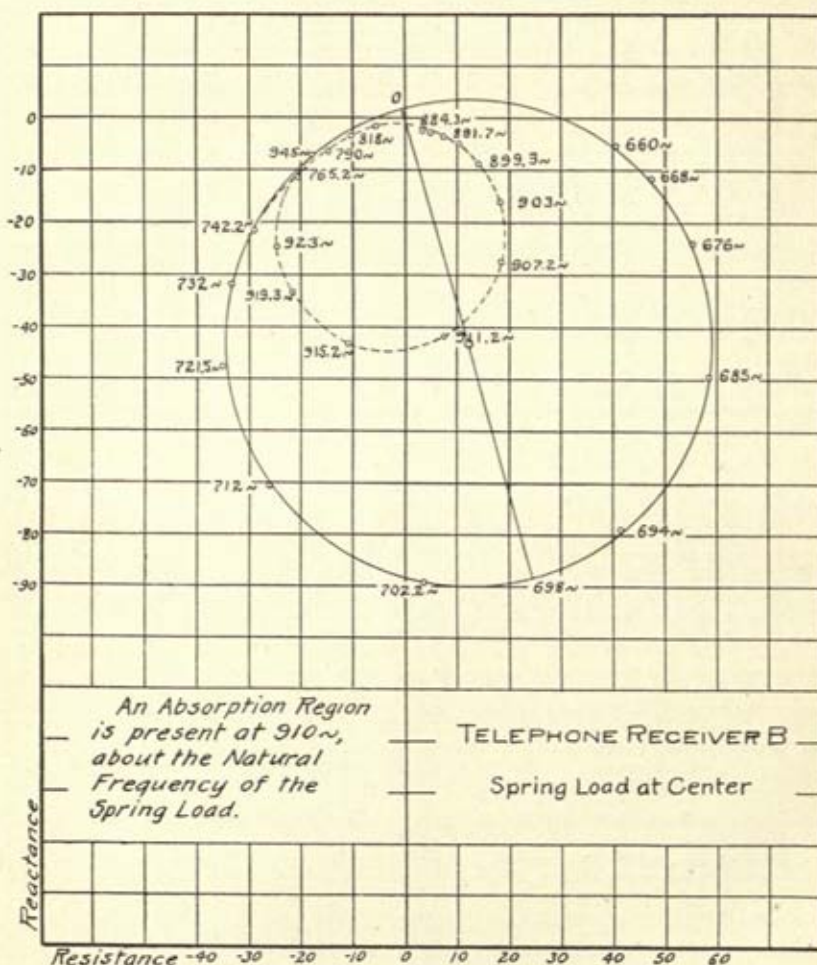


FIG. 17. Distorted Impedance Circle. Spring Load Further out of Tune with Diaphragm.

system including diaphragms properly clamped around their edges; but so connected as to possess only a single free period, will be unable to produce a distorted motional-impedance circle.

TORSION-PENDULUM MODEL FOR ILLUSTRATING MOTIONAL VELOCITY PHENOMENA.

A psychological obstacle to the use of the motional-velocity circle conceptions, in their abstract quality, and remoteness from concrete apprehension. Thus, in the case of the telephone receiver, its motional-velocity circle is obtained through the medium of the motional-impedance circle, as determined from electrical measure-

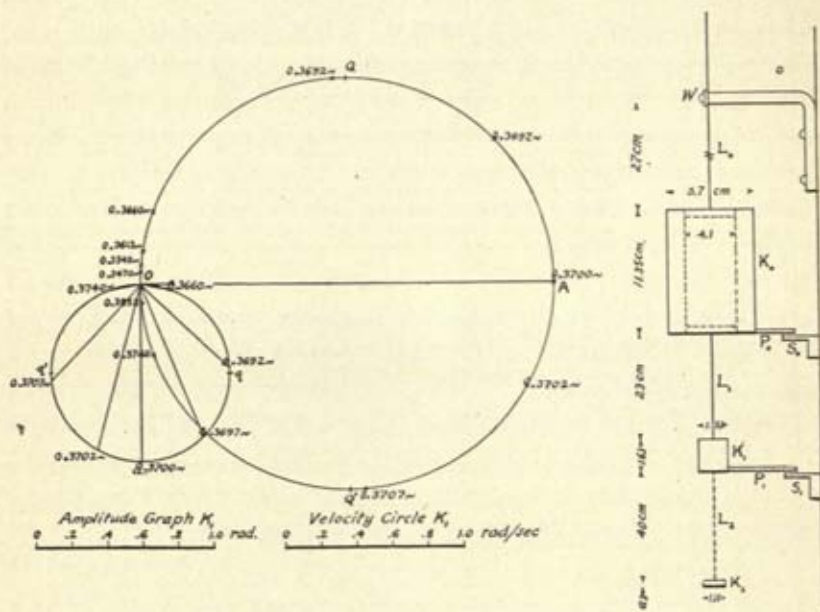


FIG. 18. Multiple Coupled Torsion Pendulum Model.

ments. It is therefore a great advantage to be able to construct a motional-velocity circle from direct observations on a simple dynamical model.

A useful and very simple dynamical model for illustrating the conditions of diaphragm vibration and the resulting motional-impedance circle has been designed and constructed as indicated in Fig. 18. It consists of a hollow brass cylinder K_0 which, in the particular model used, has a mass of 1,200 gm., a radius of gyration of 2.48 cm., and a moment of inertia of 7,470 gm.-cm.². This is suspended by a brass wire of diameter 0.76 mm., of a length ad-

justable, by means of a clamping screw w , between 10 and 40 cm., with a corresponding oscillation frequency range of 0.6 to 0.3~. The logarithmic decrement being very small, it oscillates about the suspension-wire axis with but little diminution of amplitude for several minutes. In the model used, the time constant, or the time of fall to $1/e$ th amplitude, is 216 seconds. This driving cylinder takes the place of the A.C. generator in the case of the telephone. The smaller solid brass cylinder K_1 has a mass of 26.8 gm. and a moment of inertia of 8.4 gm.-cm.². It is suspended from the driving cylinder by a smaller wire of copper, having a length usually kept constant at 23 cm., and of 0.13 mm. diameter. This driven cylinder corresponds to the telephone diaphragm, and performs oscillations of the period impressed on it by K_0 . The driving cylinder K_0 is so much larger than the driven cylinder K_1 , that the reaction of the latter is insignificant. With K_0 and K_1 in action, all the dynamical phenomena of the telephone diaphragm and its velocity circle can be observed, the frequency impressed by K_0 being adjusted by successive steps through a considerable range, by shortening up the main suspension wire L_0 . As the impressed frequency overtakes and passes the natural frequency of K_1 , with its suspension L_1 , the phenomena in the vicinity of resonance are reproduced. The K_1 system has its m , r , and s , in substantially the same manner as the oscillographic systems described in Appendix I.

Technique of Model.—In operating the model, the cylinder K_0 is first set by hand in torsional oscillation about the suspension-wire axis, with the lowest frequency of longest suspension L_0 , and with as little side swing as possible. The initial angular amplitude of K_0 may be made 90° or more. After a few oscillations, the coupled pendulum system settles down to a substantially steady state, the oscillations of K_1 having the same frequency as those of K_0 . The oscillations are allowed to subside naturally under the damping constant ($\Delta=0.00462$ hyps. per second) until a convenient standard amplitude is reached, as is indicated by a pointer P_0 , upon a suitably supported angular scale S_0 . When this happens, the eye of the observer at O can observe also the angular amplitude of K_1 as well as the angular phase-difference of the two elongations at P_0S_0 and

P_1S_1 . The decay of amplitude is so slow, that these conditions repeat themselves very closely for several oscillations above and below the standard amplitude of K_0 ; so that the observations can be repeated at several successive oscillations for an average.

The oscillation frequency of K_0 is then increased in small successive steps, by shortening up the suspension L_0 , and the above mentioned observations are repeated at each step. The amplitude of oscillation of K_1 increases rapidly as resonance is approached. In the model used, the resonant sharpness Λ is 252, but this can be controlled at will, by applying any motional resistance to K_1 which is substantially proportional to the velocity. Fig. 18 gives the angular-amplitude and angular-velocity circles for the model. It is seen that the semicircular range of resonant frequency, as computed from the circle diagram, is between $0.3692 \sim$ at ω_1 and $0.3707 \sim$ at ω_2 . For impressed frequencies below this range, the oscillation of K_1 comes nearly into cophase with K_0 . On the other hand, at impressed frequencies above this range, the amplitude of K_1 comes nearly into opposite phase with K_0 . At resonance, the oscillation of K_1 is in quadrature with the amplitude of K_0 ; or the angular velocity of K_1 will be in cophase OA with the vector torsional force or vibromotive force (V.M.F.) exerted by the wire on K_1 . This V.M.F. is proportional to the angular displacement between the ends of L_1 , and the observations obtained must be corrected to constant maximum cyclic V.M.F.

A student working with the model in the above described manner, can acquire a concrete conception of a motional-velocity circle, based upon direct observations of oscillations executed so leisurely that they are easily observed directly by the eye, without the use of reflecting mirrors or of electrical apparatus. Moreover the oscillations are sufficiently large to be perceived directly by a large class. When K_1 oscillates in air, the motional resistance r seems to increase somewhat with the amplitude. When K_1 was allowed to oscillate in water, the motional resistance was found to be more nearly constant.

When it is desired to study the phenomena of absorption, a secondary torsion pendulum L_2K_2 is attached to K_1 . It is then convenient to adjust the natural frequency of the secondary pendulum

K_2 into approximate coincidence with that of K_1 . Under these conditions, the phenomena of absorption, at or near resonance, can be readily observed. It has been possible in this manner to check the causes and essential characteristics of telephone-diaphragm absorption.

ABSORBING INFLUENCE OF THE AMPLITUDE MEASURER ON THE VIBRATION OF A DIAPHRAGM.

It was observed in the course of the preceding tests, in which the amplitude measurer was successively on and off the receiver, that the application of the device, apart from the warping effect of its clamps, slightly diminished the diameter of the impedance circle. In one case, this diameter, without the explorer, was 100.6 ohms, and with the explorer 92.5, all other conditions remaining unchanged. In other words, the application of the amplitude measurer reduced the vibrational velocity and vibrational amplitude about 8 per cent., without appreciably affecting the other constants of the instrument. This shows that when precision is needed, the motional-impedance circle should be taken with the amplitude measurer both on and off successively. The difference between the two motional-impedance diameters will indicate what correction should be applied to the measured amplitudes.

In conclusion, the authors desire to express their acknowledgments to Professor C. A. Adams and Mr. A. A. Prior, for their collaboration in the analysis of an oscillograph; also to Dr. G. A. Campbell for valuable criticisms and suggestions on the MSS.

APPENDIX I.

OUTLINE THEORY OF THE BIFILAR OSCILLOGRAPH AND DUDELL VIBRATION GALVANOMETER.¹¹

It is assumed that the apparatus consists of a bifilar vertical suspension, of adjustable tension, part of which suspension vibrates in a fairly uniform magnetic field. The two vertical wires of the

¹¹ This theory is substantially the same as that developed in the Kennelly and Affel paper (Bibliography, 10), with respect to vibrating diaphragms, replacing translatory forces by corresponding couples.

suspension carry the testing current, and are connected mechanically by a small mirror, which optically serves to indicate the angular displacement of the bifilar system at the mirror. It is further assumed that the restoring torque is $s\theta$ dyne-perpendicular-cm.,¹² proportional to the angular displacement θ radians; that the resisting torque dissipating the energy of motion is $r\dot{\theta}$, or is proportional to the angular velocity $\dot{\theta}$ radians per second; also that the inertia torque, resisting change of angular displacement, is $m\ddot{\theta}$, where m is the equivalent moment of inertia of the system at the mirror, and $\ddot{\theta}$ is the angular acceleration in radians per sec.². The impressed displacing torque, or vibromotive torque (V.M.T.), is assumed to be simply harmonic of the type

$$f = I_m A e^{j\omega t} = iA, \text{ dyne perp. cm. } \angle, \quad (1)$$

where i is the complex instantaneous current passing through the suspension, with maximum cyclic value I_m absamperes. A is the torque constant of the instrument, in dyne perp. cm. per absampere, $j = \sqrt{-1}$, $\omega =$ the impressed angular velocity, and t is the time in seconds from the moment when the real component of i starts positively through zero towards its maximum cyclic value. The real component of (1) is the instantaneous torque. The equation of motion is

$$m\ddot{\theta} + r\dot{\theta} + s\theta = f, \text{ dyne perp. cm. } \angle, \quad (1)$$

whence, in the steady state, *i. e.*, neglecting the exponentially decaying transient term,

$$\dot{\theta} = \frac{f}{r + j\left(m\omega - \frac{s}{\omega}\right)} = \frac{f}{z}, \quad \frac{\text{radians}}{\text{sec.}} \angle. \quad (3)$$

Here z is the mechanical impedance of the vibratory system. In the ordinary bifilar oscillograph, none of the four constants A , m , r and s is supposed to change, except through accidental changes of temperature. In a vibration galvanometer, however, the tuning of the vibratory system imposes changes in the impedance z , and in its

¹² In a torque τ , dyne-perp.-cm., the force f_1 dynes is assumed to act perpendicularly to the radius arm 1 cm., at which it is applied. A torque is therefore not properly expressible as dyne-cm., but as dyne perpendicular cm.; or dyne \perp cm.

components, especially in the elastic constant s .

From 3, we have

$$\theta = \frac{\dot{\theta}}{j\omega} = \frac{f}{j\omega \left\{ r + j \left(m\omega - \frac{s}{\omega} \right) \right\}}, \quad \text{radians } \angle \quad (4)$$

The instantaneous E.M.F. overcoming the counter E.M.F. of vibration is

$$e_x = A\dot{\theta} = \frac{Af}{z} = \frac{A^2i}{z} = iZ, \quad \text{abvolts } \angle, \quad (5)$$

where Z is the motional-impedance of the instrument.

Hence, at resonance,

$$A\dot{\theta}_m = I_m Z_m, \quad \text{abvolts,} \quad (6)$$

and

$$A = \frac{I_m Z_m}{\dot{\theta}_m} = \frac{I_m Z_m}{\omega_0 \theta_m}, \quad \frac{\text{dyne perp. cm.}}{\text{absampere}}, \quad (7)$$

where I_m is the maximum cyclic value of the current in absamperes, Z_m is the maximum motional-impedance—which is reactanceless, or a simple resistance—and θ_m the observed maximum cyclic resonant angular displacement, in radians. The resonant impressed angular velocity at which this occurs is denoted by ω_0 radians per second.

At $\omega = \omega_0$ (4) becomes

$$\theta_m = \frac{A I_m}{\omega_0 r}, \quad \text{radians,} \quad (8)$$

whence

$$r = \frac{A I_m}{\theta_m \omega_0}, \quad \frac{\text{dyne perp. cm.}}{\text{radian per second}}. \quad (9)$$

From the motional-impedance circle of the instrument, as plotted from observations of impedance at different impressed frequencies, the decrement per second Δ , or the hyperbolic angular velocity of decay in amplitude, may be obtained, by taking half the difference between impressed angular velocities ω_1, ω_2 at the quadrantal points in the circle; or

$$\Delta = \frac{r}{2m} = \frac{\omega_2 - \omega_1}{2} = \pi(n_2 - n_1), \quad \text{hyps. per sec.,} \quad (10)$$

where n_1 and n_2 are the corresponding impressed frequencies; whence

$$m = \frac{r}{2\Delta} = \frac{r}{\omega_2 - \omega_1}, \quad \text{gm.-cm.}^2. \quad (11)$$

At these quadrantal frequencies, the deflection amplitudes will be very nearly $\theta_m/\sqrt{2}$ radians. Finally, by observing the angular velocity ω_0 of resonance, when θ_m becomes a maximum, we obtain

$$\omega_0 = \sqrt{\frac{s}{m}}, \quad \text{radians/sec.}, \quad (12)$$

whence

$$s = m\omega_0^2, \quad \frac{\text{dyne perp. cm.}}{\text{radian}}. \quad (13)$$

Consequently, all four constants A , m , r and s can be found for any assigned adjustment of the vibration galvanometer, by measuring (a) its motional-impedance Z_m in a Rayleigh bridge, to a measured alternating current I_m maximum cyclic absamperes, (b) noting the deflection θ_m in radians, at resonance, on either side of the scale zero, (c) the resonant angular velocity ω_0 and (d) the impressed frequencies at the quadrantal points n_2 , n_1 cycles per second.

Two additional checks on the above results can be obtained, if desired, (1) by passing a small measured continuous current I_s absamperes from a storage cell and measuring the steady deflection produced. If θ_s is the corresponding steady deflection obtained, in radians; then

$$s\theta_s = I_s A, \quad \text{dyne perp. cm.}, \quad (14)$$

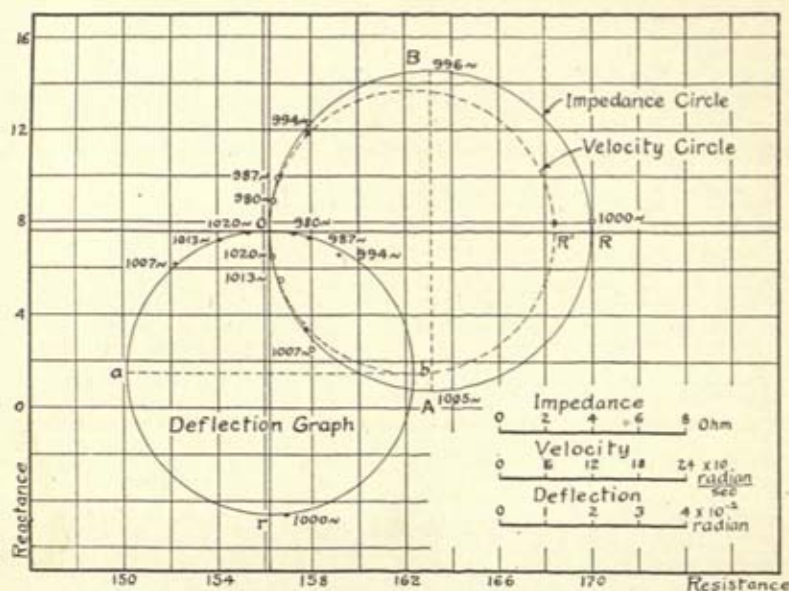
whence

$$s = \frac{I_s A}{\theta_s}, \quad \frac{\text{dyne perp. cm.}}{\text{radian}}. \quad (15)$$

It should be noted, however, that the value of s , obtained in this continuous-current test, is found to differ slightly from that found by A.C. measurements. The latter are to be preferred when available. (2) By disturbing the vibratory system, and allowing it to oscillate freely to rest, according to the formula.

$$\frac{\theta_t}{\theta_0} = e^{-\Delta t}, \quad \text{numeric}, \quad (16)$$

where θ_t is the oscillographically recorded amplitude, at a time t seconds after release, when the initial amplitude is θ_0 radians.



Observations

Freq. ~	Resist. ohm	React. ohm	Defl. rad.
980	156.3	8.95	0.0052
987	156.6	9.88	0.0087
994	157.9	12.38	0.0157
1000	170.0	8.46	0.0611
1007	158.0	2.53	0.0209
1013	156.7	5.48	0.0105
1020	156.3	6.44	0.0044

Max. Resonance Impedance, 13.8 ohms

Max. Resonance Deflection, 0.0611 rad.

Current Strength, $5.5 \cdot 10^{-4}$ amperes. rms.

Quadrantal Points at 996 and 1005 ~

Natural Frequency, 1000.5 ~

Calculations

Current, Max. Cycl. Value, $7.78 \cdot 10^{-3}$ absamp.

Max. Vib. Velocity, 383 rad/sec.

Log. Decrement, Δ , 28.3 hypos/sec.

A, Torque Const, 2804 $\frac{\text{dyne} \cdot \text{cm}}{\text{absamp}}$

m, Equiv. Moment of Inertia,
 $1,006 \cdot 10^{-5}$ gm-cm²

r, Resistance Const,
 $5,697 \cdot 10^{-4}$ $\frac{\text{dyne} \cdot \text{cm}}{\text{rad/sec.}}$

s, Elastic Const,
397.5 $\frac{\text{dyne} \cdot \text{cm}}{\text{rad.}}$

DUDELL VIBRATION GALVANOMETER.

FIG. 19. Motional-Impedance, Velocity and Deflectional Circles.

Fig. 19 shows two circular graphs starting from the common origin O, for the Duddell galvanometer used, as tuned to 1000 ~. The circle OARB is the motional-impedance circle at impressed

frequencies (obtained from a Vreeland oscillator and Rayleigh bridge), between 980 ~ and 1,020 ~. It will be observed that the maximum impedance of the instrument Z_m , at resonance, was the diametral resistance $OR = 13.8$ ohms, or 13.8×10^9 abohms. The R.M.S. current strength in the instrument was 0.55 milliampere $= 5.5 \times 10^{-5}$ absampere. The maximum cyclic current I_m was thus 7.78×10^{-5} absampere. At the impressed resonant frequency of 1,000.5 ~, the angular velocity would be $\omega_0 = 6,286$ rad./sec. Substituting in (7)

$$A = \frac{7.78 \times 10^{-5} \times 13.8 \times 10^9}{6.286 \times 10^3 \times 0.611 \times 10^{-1}} = \frac{107.4 \times 10^4}{3.83 \times 10^2} \\ = 2804 \frac{\text{dyne perp. cm.}}{\text{absampere}}.$$

The lower circle in Fig. 19, Oa and b shows the magnitudes of the deflections, each side of the scale zero, in radians of arc. The maximum observed deflection at $Or = 0.0611$ radian, was obtained, within the limits of experimental error, at the same frequency as the maximum resistance OR of the motional-impedance circle. Substituting the value of A just found in (9) we obtain

$$r = \frac{2.804 \times 10^3 \times 7.78 \times 10^{-5}}{0.611 \times 10^{-1} \times 6.286 \times 10^3} = \frac{21.82 \times 10^{-2}}{3.83 \times 10^2} \\ = 5.697 \times 10^{-4} \frac{\text{dyne perp. cm.}}{\text{rad. per sec.}}$$

The maximum cyclic displacing torque was by (1)

$$7.78 \times 10^{-5} \times 2.804 \times 10^3 = 0.2182 \text{ dyne perp. cm.}$$

The quadrantal points B and A on the motional-impedance circle are at 996 ~ and 1,005 ~, making the damping constant $\Delta = 3.142 \times 9 = 28.3$; so that the oscillations of the instrument would naturally fall to $1/e$ th, or to 36.8 per cent. of the initial amplitude, in a time constant of $1/28.3 = 0.0353$ second. Substituting this value of Δ in (11), we obtain

$$m = \frac{5.697 \times 10^{-4}}{56.6} = 1.006 \times 10^{-5} \text{ gm.-cm.}^2; \text{ or } \frac{\text{dynes}}{\text{rad. per sec.}^2}.$$

Finally from (13), we obtain

$$s = 1.006 \times 10^{-5} \times 6286^2 = 397.5 \frac{\text{dyne perp. cm.}}{\text{radian}}.$$

The reason for making the diameter Or of the deflection graph lag 90° behind the diameter OR of the impedance circle, and the diameter OR' of the velocity circle, is that according to (4), the phase of any displacement θ is 90° behind the corresponding velocity $\dot{\theta}$. Strictly speaking, while the velocity graph is a circle; the deflection graph is only approximately a circle, since in (4), the variable ω appears directly as a factor in the denominator. The angular velocity of maximum deflection ω_d is not the same as the resonant angular velocity ω_0 , but is

$$\omega_d = \sqrt{\omega_0^2 - 2\Delta^2}, \quad \frac{\text{radians}}{\text{sec.}}, \quad (17)$$

while the angular velocity of free oscillations ω_f , in the presence of damping, lies between ω_d and ω_0 ; namely

$$\omega_f = \sqrt{\omega_0^2 - \Delta^2}, \quad \frac{\text{radians}}{\text{sec.}}. \quad (18)$$

In this case, taking $\omega_0 = 6,286.0$, $\omega_f = 6,286.06$ and $\omega_d = 6,286.13$; or the damping is so small, and the resonance is so sharp, that the difference between these three important and characteristic angular velocities is very small.

We may define the *sharpness of resonance*, or *sharpness of tuning* (inverted V),¹³ in relation to the resonant and quadrantal angular velocities ω_0 , ω_2 and ω_1 by the formula¹³

$$\Lambda = \frac{\omega_0}{\omega_2 - \omega_1} = \frac{\omega_0}{2\Delta} = \frac{n_0}{n_2 - n_1}, \quad \text{numeric}, \quad (19)$$

which in this case is $6,286/56.6 = 111.1$, a relatively high figure of merit in regard to tuning.¹⁴ The reciprocal of Λ may perhaps be

¹³ Suggested by Dr. R. L. Jones. Bibliography No. 8. The expression "sharpness of tuning" has also been suggested by Barton (bibliography, 4) with a different quantitative meaning.

¹⁴ In the case of a certain experimental monopolar telephone receiver, tested by Kennelly and Pierce (bibliography, 7), the sharpness of resonance was found to be 161.2, the highest experimental value in electromagnetic apparatus yet observed in these researches.

called the *bluntness of resonance*, in this case 9.006×10^{-3} . The *semicircular range of resonance* may be expressed in angular velocity measure, as the range of angular velocity $\omega_2 - \omega_1$ between quadrantal points, or 2Δ , in this case 56.6 radians per second. The same range may be expressed also in frequency measure by $n_2 - n_1$, or the difference of frequencies at quadrantal points $= \Delta/\pi$, in this case $9 \sim$. All frequencies outside of these quadrantal points may be regarded as outside the semi-circular range of tuning. At the frequencies of these quadrantal points, n_2, n_1 , the resonant kinetic energy manifestly falls to one half.

Referring to the dotted curve $ABCDE$, Fig. 15, of the undistorted amplitude of the diaphragm's vibration, the ordinates Bb and Dd indicate the amplitudes bounding the resonant range. The expressions defining these ordinates x_1 and x_2 are:

$$\frac{x_1}{x_0} = \frac{1}{\sqrt{2}} \cdot \frac{n_0}{n_1} \quad \text{and} \quad \frac{x_2}{x_0} = \frac{1}{\sqrt{2}} \cdot \frac{n_0}{n_2}, \quad \text{numeric, (19a)}$$

These ordinates are 6.35 and 6.0 microns, respectively, in Fig. 15. The resonant range is $778 - 732 = 46 \sim$, and the resonant sharpness is thus $753.5/46 = 16.4$. It is thus possible to determine the sharpness and the range of resonance from a curve of amplitude against frequency, as well as from a circle diagram of velocity or of impedance.

The sharpness of resonance may also be defined by the acoustic interval or numerical ratio c between the quadrantal frequencies.

$$c = \frac{\omega_2}{\omega_1} = \frac{n_2}{n_1}, \quad \text{numeric. (20)}$$

In this case $c = 1.009$. We also have

$$\frac{\omega_0}{\omega_1} = \frac{\omega_2}{\omega_0} = \sqrt{c}, \quad \text{numeric. (21)}$$

This criterion c is connected with the resonant sharpness Λ by the relation

$$\Lambda = \frac{\sqrt{c}}{c - 1}, \quad \text{numeric, (22)}$$

since any pair of frequencies, lying on the velocity circle, at equal

angles on opposite sides of the resonant diameter, have the resonant frequency as their geometric mean. The acoustic criterion c is, however, in general, less satisfactory than the resonant sharpness Λ ; because the greater the resonant sharpness the greater becomes Λ but the smaller becomes c .

From an examination of Fig. 19, it is evident that, at resonance, the phase of the deflection or angular displacement of the mirror is just 90° behind the phase of the angular velocity, and of the current in the instrument. If OR represents the current phase; then, at resonance, Or is the phase of the mirror's maximum elongation. At impressed frequencies below $980 \sim$, the phase of displacement in the deflection graph is almost exactly coincident with that of the current. On the other hand, at impressed frequencies above $1,020 \sim$, the phase of displacement is almost exactly opposite to, or 180° removed from, that of the current.

An attempt was made to ascertain how the constants A , m , r and s of the Duddell instrument varied with different tuning and lengths of free suspension. It was found, however, that owing to some friction in the suspension pulley, the tension of the two wires did not equalize sufficiently to prevent the appearance of partial unifilar characteristics, which vitiated the results. Such departures from pure bifilarity would not, however, affect the above mentioned phase relations between displacement and current.

A similar set of measurements may be applied to an oscillograph. The normal alternating-current strength required to operate the oscillograph may, however, be greater than can conveniently be supplied through a Rayleigh bridge, as used for testing telephones or vibration galvanometers. In that case, a convenient technique is to supply a measured R.M.S. current from a Vreeland oscillator to the oscillograph vibrator, and observe the amplitude of the mirror's deflection thereby produced, on each side of the zero, reducing the same to radian measure from the geometry of the optical system. The angular velocity ω_0 radians per second, necessary for maximum resonance, has to be carefully observed, and at the same time the maximum resonant mirror deflection θ_m radians. This gives equations (8) and (12). The frequency is then gradually changed until the deflection is reduced in the ratio $1/\sqrt{2}$, the change being made

first by raising the frequency slightly above resonance, and then lowering it. These measured angular velocities ω_2 and ω_1 correspond to the quadrantal points on the motional-impedance circle, and supply Δ by formula (10). Finally, the continuous-current strength, I_s abamperes, necessary to produce a steady mirror deflection θ_s radians, is measured as in (14). These four equations suffice to evaluate A , m , r and s for the instrument. An oscillographic natural decay curve, corresponding to (16), may also be taken as a check on the results.

The following are the results of a series of observations made on an experimental bifilar oscillograph¹⁵ with two strips, each of active length 3.5 cm. in a magnetic field of approximately 16 kilogausses. The strips were of phosphor bronze, 0.366 mm. wide (15 mils), and 0.013 mm. thick (0.5 mil), each under a tension of approximately 30 gm. weight, spaced 1.5 mm. on centers, and having a mirror fastened to and across them, about 1 mm. \times 0.5 mm., near the middle of their active length. The vibrator was air damped, *i. e.*, it did not work in oil.

$$\begin{aligned} A &= 3,750 \text{ dyne perp. cm. per abampere,} \\ n_0 &= 2,530.5 \sim, \omega_0 = 1.59 \times 10^4 \text{ radians/sec.,} \\ m &= 1.322 \times 10^{-5} \text{ gm.-cm.}^2, \\ r &= 2.78 \times 10^{-3} \text{ dyne perp. cm. per radian per sec.,} \\ s &= 3,360 \text{ dyne perp. cm. per radian,} \\ n_2 &= 2,547 \sim, \quad n_1 = 2,514 \sim, \\ \Delta &= 103.7 \text{ hyps. per sec.,} \\ \Lambda &= 76.7, \\ n_2 - n_1 &= 33 \sim, \\ \theta_s / I_s &= 1.115 \text{ radians per abampere,} \\ I_m &= 0.002 \text{ absampere,} \\ Z_m &= 5.075 \times 10^9 \text{ abohms} = 5.075 \text{ ohms.} \end{aligned}$$

By plotting the deduced angular velocities $\dot{\theta}$ at different impressed frequencies close to resonance, a fairly good circular locus was obtained. The diagram is the same as that of Fig. 19, except as to the scales of magnitude and numerical values.

¹⁵ Bibliography, 11.

APPENDIX II.

OUTLINE THEORY OF THE ABSORPTION DIAGRAM.

The following provisional theory was arrived at by searching for a quantitative expression that would satisfy the impedance diagrams when distortion was present. It bears a close analogy to the theory of alternating-current coupled circuits in the steady state.

The equation for the ordinary motional-impedance circle, considered as representing a vibration velocity circle, and neglecting the depression angles β_1^0 and β_2^0 is¹⁶

$$\dot{x}_m = \frac{AI}{z} = \frac{F}{z} = \frac{F}{r + j\left(m\omega - \frac{s}{\omega}\right)} \quad \text{max. cyclic kines } \angle, \quad (23)$$

where

$F = AI$ = the maximum cyclic V.M.F. to standard phase, dynes \angle ,

A = force constant of the receiver, dynes/absampere,

I = maximum cyclic current strength, absamperes,

r = mechanical resistance of diaphragm, dynes/kine,

m = equivalent mass of diaphragm, gm.,

s = elastic constant of diaphragm, dynes/cm.,

z = mechanical impedance, dynes/kine \angle ,

$\omega = 2\pi n$, impressed angular velocity, radians/sec.,

ω_0 = resonant angular velocity, radians/sec.,

n = impressed frequency, cycles/sec.,

n_0 = resonant frequency, cycles/sec.,

$j = \sqrt{-1}$,

x_m = mechanical displacement amplitude of diaphragm,

max. cyclic cm. \angle ,

\dot{x}_m = vibrational velocity of diaphragm, max. cy. kines \angle .

When the vibrating diaphragm supplies motional power to a dependent vibrational system, having its own natural frequency n_{02} , and therefore its own mechanical constants z_2 , m_2 , r_2 and s_2 , the dependent or secondary system will exert a max. cyclic counter vibromotive force (C.V.M.F.) — f_2 , on the driving force F ; so that the resulting equation of motion becomes

¹⁶ Bibliography, 9.

$$\dot{x}_a = \frac{F - f_2}{z} = \dot{x}_m - \dot{x}_2, \quad \text{kines } \angle, \quad (24)$$

where \dot{x}_a is the max. cyclic velocity of the diaphragm in the presence of absorption. The C.V.M.F. f_2 is proportional to the velocity \dot{x}_a , to the mechanical resistance r_2 of the dependent system, and to the relative phase of \dot{x}_2 and r_2 , as defined by the complex ratio r_2/z_2 .

That is,

$$f_2 = \dot{x}_a r_2 \left(\frac{r_2}{z_2} \right) = \dot{x}_a \frac{r_2^2}{z_2}, \quad \text{max cy. dynes } \angle. \quad (25)$$

The secondary C.V.M.F. f_2 will therefore be out of phase with the velocity \dot{x}_a of the diaphragm, except at the frequency n_{02} of secondary resonance, when $z_2 = r_2$; and

$$f_{02} = \dot{x}_a r_2, \quad \text{max cy. dynes } \angle. \quad (26)$$

Substituting (25) in (24), we obtain

$$\dot{x}_a = \frac{F - \dot{x}_a \frac{r_2^2}{z_2}}{z}, \quad \text{max cy. kines } \angle, \quad (27)$$

whence

$$\dot{x}_a = \frac{F}{z + \frac{r_2^2}{z_2}} = \frac{F}{z + z_a}, \quad \text{max cy. kines } \angle. \quad (28)$$

The effect, therefore, of the dependent system having a secondary resonant frequency is to add a new *absorption impedance*

$$z_a = r_2^2/z_2$$

to the primary impedance z .

Solving (24) for \dot{x}_2 the absorption or secondary velocity we obtain

$$\dot{x}_2 = \left(\frac{F}{z} \right) \frac{z_a}{z + z_a} = \dot{x}_m \left(\frac{z_a}{z + z_a} \right), \quad \text{max cy. kines } \angle. \quad (29)$$

From an examination of (28), it is evident if the primary and secondary frequencies are tuned to coincide, i. e., if $n_{02} = n_0$, then at this frequency, $z_2 = r_2$ and $z = r$, so that

$$\dot{x}_a = \frac{F}{r + r_2}, \quad \text{max cy. kines } \angle. \quad (30)$$

In this case, the velocity, in the presence of distortion, is in phase

with the impressed force at the doubly resonant frequency; but is less than it would be in the absence of the secondary system, in the ratio $r/(r+r_2)$. Moreover, at all other frequencies, the resulting

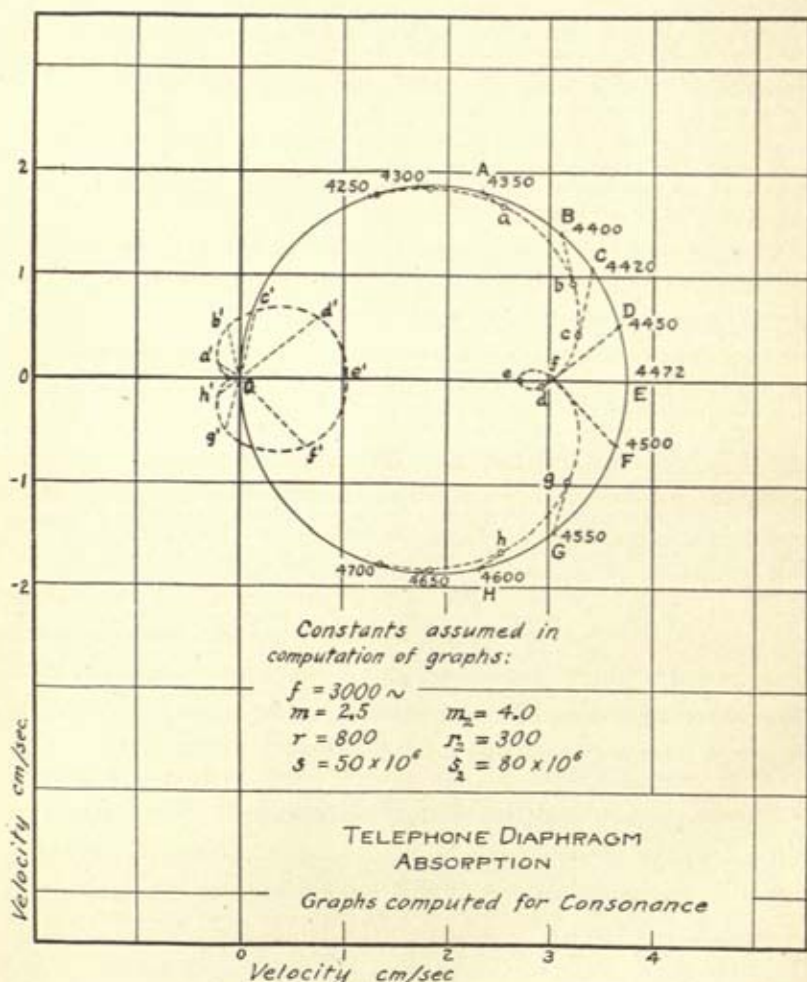


FIG. 20. Computed Distorted Velocity Circle.

velocity \dot{x}_a is less than the normal velocity. The secondary velocity \dot{x}_2 is greatest at the doubly-resonant frequency, and falls off rapidly as this frequency is departed from on either side.

Fig. 20 gives the computed graphs for a particular case, where $ABCDH$ is the normal-velocity circle \dot{x}_m , in heavy line, and $abcdh$

of \dot{x}_a is the distorted velocity graph; also $a'b'c'd'h'$ of \dot{x}_2 is the absorption velocity graph, reckoned negatively. At any impressed angular velocity, such as 4,450 radians per second, the undistorted or primary velocity \dot{x}_m would be OD cm. per sec., leading the impressed V.M.F. by the angle EOD . The observed velocity \dot{x}_a , in the presence of distortion, is Od ; while the vector difference between the \dot{x}_m and \dot{x}_a , or Dd , is equal to $\dot{x}_2 = -Od'$ or Od' reversed.

It will be observed that the graph of \dot{x}_2 , $a'b'c'h'$ is only approximately a circle. It may be regarded, in the light of (29), as the graph of a vector fraction of a motional circle.

It should also be noted from (28) that when the primary and secondary resonant frequencies differ, the resultant velocity \dot{x}_a will not come into phase with the V.M.F. at either resonance frequency, but will trace a dissymmetrical loop. The absorption velocity graph $a'b'c'h'$ will be likewise dissymmetrical.

Fig. 6 shows the observed graph $Oabch$ of motional impedance, and therefore of velocity, with reference to an impressed force in the vector direction OE . The heavy circle $OABCH$ is the inferred undistorted or primary graph, as deduced from the segment AOH . The foliate graph $Oa'b'c'h'$ is the vector difference, or secondary graph of absorption. It will be observed that except for a slight difference in the primary and secondary resonant frequencies, the case presented in this test agrees closely with the geometrical relations indicated in Fig. 20.

Referring to Figs. 7 and 8, it will be observed that the angle AOC is approximately equal to the angle COF . This means that, at secondary resonance, the absorption velocity OF lies nearly as far in angle beyond the vector OC , of that frequency on the undistorted circle, as OC lies from OA the mean diameter. Formula (29) gives a ready explanation for this; because at secondary resonance $s_a = r_2$, so that

$$\dot{x}_2 = \dot{x}_m \left(\frac{r_2}{s + r_2} \right), \quad \text{kines } \angle. \quad (31)$$

If, as in the cases represented by Figs. 7 and 8, r_2 is small by comparison with s , this becomes approximately

$$\dot{x}_2 = \dot{x}_m \left(\frac{r_2}{s} \right), \quad \text{kines } \angle. \quad (32)$$

or the vector $\dot{x}_2 = OF$, is displaced from the vector $\dot{x}_m = OC$ by a phase angle equal to the angle of the primary impedance z , which is itself the angle AOC . In other words, the factor r_2/z is a complex quantity whose argument is the negative of that of z . Owing to the presence of r_2 in the denominator of (31), the angular deviation of \dot{x}_2 from \dot{x}_m will be always somewhat less than the angle AOC of z ; so that the vector CE parallel to FO of secondary resonance, always intersects the diameter OA at a point a little nearer to the origin than the center of the main impedance circle.

The theory also explains why a distortion loop, when the secondary frequency is much below the primary frequency, is very small, and near to the origin on the right; also, as the resonant frequencies are made to approach, the loop enlarges, falling nearer to the main diameter, and finally, as the resonant frequencies pass each other and again diverge, the loop shrinks in size, and passes off towards the origin on the left. In (29), if secondary resonance occurs much above or below primary resonance, the loop due to this resonance will appear remote from the diametrical point A , z_2 again reduces to r_2 and

$$\dot{x}_2 = \frac{F}{z} \left(\frac{r_2}{z + r_2} \right), \quad \text{kines } \angle, \quad (33)$$

since r_2 is then certainly small by comparison with z , this is approximate to Fr_2/z^2 ; or varies inversely as the square of the impedance modulus. On the other hand, as the primary and secondary resonances approach, z approaches r , and x_2 finally attains a maximum possible value at $Fr_2/r(r + r_2)$. If $r_2 = pr$, this becomes

$$\dot{x}_2 = \frac{F}{r} \left(\frac{p}{p + 1} \right) = \dot{x}_m \left(\frac{p}{p + 1} \right), \quad \text{kines } \angle. \quad (34)$$

This shows that in order to have a secondary absorption velocity nearly equal to the primary velocity, it is necessary to have the two resonant frequencies n_0 and n_{02} nearly coincident, and p large by comparison with unity; or the secondary resistance large by comparison with the primary resistance. In such a case, if the two frequencies do not quite coincide, there will be nearly zero velocity and amplitude near to the secondary frequency and a maximum velocity on each side of this, as in Figs. 14 and 15.

SUMMARY.

1. The depression angles β_1° and β_2° of the diameter of a telephone receiver's motional-impedance circle are not closely connected, and are differently affected by impressed frequency. In some cases β_1° was found to be the greater, and in others β_2° . Increase in frequency increased β_1° . Neither angle was markedly affected by changes in air-gap. The relations between β_1° and β_2° may be conveniently studied by means of Lissajous figures.

2. Both the vibration galvanometer, and the oscillograph, have a motional-impedance circle, and a corresponding useful series of motional constants A , m , r and s . Tests were made on well-known types of these instruments, and their theory is outlined in Appendix I.

3. The motional-impedance circle of a telephone receiver may sometimes reveal a distortion, accompanied by an absorption and a suppression of power. The distortion is ordinarily a reëtrant loop. It may also be a general shrinking of velocity, over a considerable range of frequency, accompanying a flattening of the impedance circle.

4. A distortion in the form of a reëtrant loop is attributable to the existence of a secondary or dependent vibratory system, having its own motional constants and resonant frequency. The invading loop may in particular cases be so large as almost to bring the motional impedance to zero near the main diameter. In such a case, there will be two frequencies of markedly large amplitude, one on each side of the frequency of greatest absorption.

5. A distortion in the form of a general flattening of the impedance circle might be accounted for by the existence of secondary vibration in a dependent attached system, not having a definite natural frequency.

6. The dissymmetrical clamping of an amplitude measurer to the cap of a telephone receiver may introduce such deformation of the clamping circle as will give rise to a reëtrant loop or loops. Care should therefore be taken to avoid introducing dissymmetrical stresses when applying such an instrument to a receiver.

7. A dependent motional system, consisting of a short strip spring

fastened to the center of a telephone diaphragm, and tuned nearly into consonance therewith, gave rise to a large reëtrant loop.

8. A provisional but apparently satisfactory theory of loop distortion is given in Appendix II.

9. An experimental form of coupled multiple pendulum is described, which affords a visual manifestation of the essential phenomena of the motional-impedance circle, and of its loop distortions.

10. Means are described for applying a correction for the absorption due to the use of an amplitude measurer, when determining the motional constants A , m , r and s of a telephone receiver.

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LIST OF SYMBOLS EMPLOYED.

- A Torque constant of a vibration galvanometer or oscillograph (dyne-perp.-cm. per absampere). Also force constant of a telephone receiver (dynes per absampere).
- $c = n_2/n_1$ Acoustic interval between quadrantal frequencies (numeric).
- Δ Damping constant, a hyperbolic angular velocity (hyp. radians per sec.).

e_s	Instantaneous emf. opposite and equal to cemf. of motion (abvolts \angle).
$e = 2.71828$	Base of Napierian logarithms.
f	Instantaneous vibromotive force or torque (dynes) or (dyne-perp.-cm.).
f_1	Force entering into a torque (dynes).
f	Maximum cyclic vibromotive force or torque, (dynes) or (dyne-perp.-cm.).
f_2	Maximum cyclic counter V.M.F. of absorption (dynes \angle).
θ	Angular deflection of vibrator mirror (radians \angle).
θ_m	Maximum angular deflection at resonance (radians).
θ_0	Initial amplitude of angular deflection at moment of release (radians).
θ_s	Steady angular deflection produced by a continuous current (radians).
θ_t	Amplitude of angular deflection at time t after release (radians).
$\dot{\theta}$	Complex instantaneous angular velocity (radians/sec. \angle).
$\ddot{\theta}$	Complex instantaneous angular acceleration (radians/sec. ² \angle).
I	A continuous current strength (absamperes).
I_m	Maximum cyclic current in the vibrator (absamperes).
i	Complex instantaneous current strength (absamperes \angle).
$j = \sqrt{-1}$	
l	Length of radius arm on which a torque acts (cm.).
m	Moment of inertia of vibrating system (gm.-cm. ²). Also mass of linear vibration system (gm.).
m_2	Mass of a secondary linear vibration system (gm.).
n	Impressed frequency (cycles per sec.).
n_0	Resonant frequency (cycles per sec.).
n_1	Frequency at earlier quadrantal point in motional circle (cycles per sec.).
n_2	Frequency at later quadrantal point in motional circle (cycles per sec.).
$p = r_2/r_1$	Ratio of secondary to main mechanical resistance (numeric).
$\pi = 3.1416$	
r	Torque of resistance to angular velocity (dyne-perp.-cm./radian per sec.). Also resistance to vibrational motion of a diaphragm (dynes/kine).
r_2	Resistance of secondary or dependent system to motion (dynes/kine).
s	Torque of angular displacement (dyne-perp.-cm./radian). Also elastic constant of linear vibration system (dynes/cm.).
s_2	Elastic constant of secondary linear vibration system (dynes/cm.).
t	Elapsed time (secs.).
τ	Torque (dyne-perp.-cm.).
$\Lambda = \omega_0/2\Delta$	Resonant sharpness, or sharpness of tuning (numeric).

x	Instantaneous displacement of diaphragm (cm.).
x_m	Max. cyclic displacement of diaphragm (cm.).
\dot{x}	Complex velocity of diaphragm (cm./sec.).
\dot{x}_m	Max. cyclic velocity of diaphragm (cm./sec.).
\dot{x}_a	Max. cyclic velocity of diaphragm in presence of absorption (cm./sec.).
\dot{x}_2	Max. cyclic complex velocity of secondary system (cm./sec.).
Z	Motional impedance of vibrator (absohms \angle).
Z_m	Maximum motional impedance at resonance (absohms).
z	Torque of mechanical impedance to angular velocity (dyne-perp.-cm./rad. per sec. \angle). Also force of mechanical impedance to diaphragm velocity (dynes/kine \angle).
z_2	Mechanical impedance of secondary system (dynes/kine \angle).
$z_a = r_2^2/z_2$	Change of primary mechanical impedance, due to presence of the absorption or secondary system (dynes/kine \angle).
$\omega = 2\pi n$	Angular velocity of impressed frequency (radians per sec.).
$\omega_0 = 2\pi n_0$	Angular velocity of resonance (radians per sec.).
$\omega_1 = 2\pi n_1$	Angular velocity of earlier quadrantal point on motional circle (radians per sec.).
$\omega_2 = 2\pi n_2$	Angular velocity of later quadrantal point on motional circle (radians per sec.).
$\omega_d = 2\pi n_d$	Impressed angular velocity producing maximum angular deflection (radians per sec.).
$\omega_f = 2\pi n_f$	Angular velocity of free oscillation (radians per sec.).
\cong	Nearly equal to.
ab. or abs.	Prefix indicating a C.G.S. magnetic unit.
kine	1 cm./sec.
V.M.F.	Vibromotive force.
\angle	Indication of a complex unit.

THE NORMAL GASTRIC SECRETION.

By MARTIN E. REHFUSS, M.D.

(Read April 14, 1916.)

The human gastric secretion has been the subject of persistent study ever since it was realized that there was apparently secreted a free mineral acid in the stomach. Not only has this fact, the presence of a true acid secretion, given rise to endless discussion, but the mechanism of gastric digestion has been attacked from every angle. The x-ray and especially the fluoroscope has thrown much light on gastric movements but has left us hopelessly in the dark as to the intimate chemistry and the respective physico-chemical changes which occur while the kaleidoscopic changes in form are recorded. It has until very recently been practically impossible to investigate either normal or pathological digestion satisfactorily in man. The fundamental principles were laid down by the painstaking work on fistulas on animals by the Pavlov school and a host of investigators who recorded many observations in man by means of the old stomach tube. With the exception of a few fistula cases such as the historic instance of Alexis St. Martin and the occasional case of gastric fistula consequent to an acquired stenosis of the esophagus there are no coordinated observations on normal digestion in man. This was owing to the lack of a method by which it was possible to follow every phase of gastric digestion. In spite of the lack of a method, the use of the bulky and wholly undesirable stomach tube was followed and many observations were made.

In the fall of 1913, while studying the work of Hayen, I endeavored to find a tube which could be introduced into the stomach and left in place. The original tube was a modification of the Einhorn tube, but it was neither sufficiently heavy nor of sufficient calibre for this purpose. I then devised a special tip olivary in type and of such a form as to be easily swallowed and of sufficient weight to seek the bottom of the stomach, or the most dependant portion of

the greater curvature of the stomach by gravity. A number of tips were made, but finally one was found which was the most satisfactory—and it was slotted in such a way that the diameter of the slots represented the maximum bore of the rubber tubing. This in turn was glass molded in order that it gave rise to no irritation while in situ. This tube was swallowed in the natural way: it gives rise to practically no irritation and I was able to satisfy myself by radioscopic examination that it reaches the lower part of the stomach. Another important feature was the fact that this tube could be left in place for hours with practically no discomfort and that it constituted practically a "via ouvert" or a direct communication to the stomach at all times so that the progress of digestion could be accurately followed and the examination of the material removed faithfully recorded. For the first time it was possible to follow every step in the chemical evolution of digestion and at the Jefferson Medical College, under the supervision of Dr. Hawk and with the collaboration of Drs. Bergeim, Fowler, Spencer, Clarke and others, we began an extensive survey of normal and pathological digestion.

Before discussing the important findings regarding gastric digestion, the first salient feature which became apparent was the impossibility of interpreting the findings of a single examination of the stomach as determined by the old method. In a communication to the *Journal of the American Medical Association*, Vol. LXIV., pp. 567-573—I made the following statement which has been since confirmed by other workers (Carroll, Pollock, Talbot):

1. It is impossible to interpret the figures obtained by the examination of the test meal removed in one hour time by the usual technic.
2. The one hour period represents but one phase in the constantly changing cycle of gastric digestion.
3. It is absolutely impossible to judge from the old method what has preceded or what will follow this point.

We were able to show for instance that normal figures at the one hour point may be preceded or followed by entirely different phenomena in the brief course of 10 or 15 minutes and that for an accurate analysis of the phenomena, it is essential that we make an examination at every interval during digestion. This method of

examination, I have called the "fractional examination or determination of gastric digestion," because it consists in removing at intervals a fractional portion of the actively changing gastric contents for examination. From the material which is removed by aspiration, by newer methods a complete chemical, bacteriological and cytological examination may be made and curves constructed representing the progress of gastric digestion.

By means of this tube, the first important observation which we made was the nature of the material found in the empty stomach. It has been generally considered that this material should not exceed 20 c.c. in health. We found in a study of over 100 normal medical students, that the quantity of material in the empty stomach practically always exceeded this point and in the above series, the average was 52.14 c.c., more than twice the quantity formerly considered normal. We found furthermore that this material was in most instances a physiologically active secretion capable of inducing gastric digestion and giving as average figure for the above series a total acidity of 29.9 in terms of N/10 NaOH necessary to neutralize 100 c.c. of secretion (phenolphthalein) and 18.5 free acidity (Sahl method). Pepsin determination in 53 cases gave an average of (2.8). We were further able to demonstrate by means of a special method devised in our laboratories the presence of trypsin almost constantly in the residuum, which was shown to be inversely proportional to the free acidity.

In other words we found at whatever time we examined the stomach regardless of the presence or absence of food a physiologically active secretion in the stomach. If as was performed on several occasions, we removed the complete residuum and then without introducing food in the stomach examined the organ somewhat later, a physiologically active secretion could be removed even though in digestive power it was lower than the material seen during the digestive periods. In health therefore it is correct to assume that there is always a minimal secretion in the stomach which at regular intervals undergoes perturbations due to the influence of hunger, psychic influences of sight, taste, and smell of food, and finally the complex digestive cycle following the introduction of food into the stomach.

We found this "residuum" of the empty stomach one of the lightest fluids in the body with an average specific gravity of 1.0056 and an average cryoscopic index of -0.470 which when compared to the index of blood -0.560 seems to indicate a tendency for osmosis of material to take place from the blood into the lumen of the stomach. We found bile in almost one half the normal residua, and this phenomenon may be present or absent in the same individual without any subjective phenomena whatsoever.

We then made an investigation of many substances in the stomach of the normal healthy subject and used for that purpose water, meat extracts, tea, toast and since that time many of the various food-stuffs concerning which we shall have more to say in the future. In a convincing series of experiments on water it was immediately evident that water is a strong gastric stimulant and while it may be true that the bulk of the liquid leaves the stomach in the first twenty minutes along the "rinne" of the lesser curvature, we found that water either cold or warm is a strong gastric stimulant, yielding an acidity in certain instances of over 100 in less than twenty minutes. In the normal individual on many occasions water produced fully as great stimulation as an Ewald meal of toast and tea so that it became a serious question as to whether or not the stimulative effect of an Ewald meal was not due to its water content, but the dry toast induced a very definite characteristic secretion.

In our studies we were unable to demonstrate two essential points which have previously been considered as belonging to the phenomena of digestion. It was impossible to demonstrate any "latent period" for the human gastric glands, as Pavlov demonstrated in animals and secondly—it was impossible to demonstrate any glandular fatigue which Foster and Lambert attempted to point out. In the water series despite any possible dilution of the water introduced we obtained figures of from 50–120 (0.18–0.44 per cent. HCl) with an average of 77 (0.28 HCl) considerably over that ordinarily considered normal for man. It is probable that the juice secreted at the height of digestion is distinctly higher than that usually considered and the contention of Umber, Bickel, Sommerfeld, Hornberg and others that the gastric juice of man is very similar (0.4–0.5 per cent.) to the gastric juice of the cat* and dog is true.

Some time ago Dr. Hawk and I published a paper on the direct evidence of the secretion of a gastric juice of constant acid concentration in the human subject. We have been criticized for considering the "digestive" plateau while food was in the stomach as evidence of this. On the contrary however—the evidence when there is no food in the stomach namely the "plateau" or "constant acid level" seen in certain cases after water introduction, presumably after all water has left the stomach or when the diluting action of water can be no longer felt and again the "constant acid secretion"—frequently seen after all food has left the stomach are the most powerful arguments for the secretion of a constant acid grade.

NORMAL SECRETORY CURVE.

For the investigation of gastric disturbances it becomes absolutely essential that we have a standard, any deviation from which constitutes a pathological finding. Such an arbitrary and concrete standard is obviously impossible because in every individual there is a characteristic functional output. It is possible to draw the limits of health for any group of individuals, but practically every group of bodily functions undergoes many variations owing to a multitude of variable factors in the course of the day. Under exact conditions the output is the same, but exact conditions are somewhat difficult to approximate. From a very large series of observations on normal healthy medical students, the following statements seem entirely justifiable:

- (a) Each individual has a characteristic gastric response.
- (b) Under identical conditions, physical and environmental, the type and character of the gastric response to a certain stimulus is essentially the same.
- (c) There are several varieties of normal secretory response, normal in that they are found in individuals absolutely free from gastrointestinal symptoms and to all intents and purposes enjoying perfect health.

We have tried various meals but for simplicity, availability and short gastric transit we have studied the Ewald meal 35 grams of toast and 240 c.c. of weak tea or water in an attempt to outline the normal gastric response.

We found that healthy medical students reacted to the Ewald meal in one of three ways:

1. The "isosecretory" type shows a steady rise, high point, in terms of tenth-normal sodium hydroxid, 60, usually sustained for from half an hour to an hour, and then a gradual decline with a total disappearance of the food residues in from two to two and one half hours.

The curve is usually steady and unbroken; its high point is usually rounded and not abrupt and is to be found in the neighborhood of one hour.

2. The "hypersecretory" type shows a rapid response to stimuli, often a marked change in the acidity even of the five-minute samples, rapid increase in acidity, high point from 70 to 100 or over, either sustained or abrupt, and a slow decline or none at all in the usual time. The food left the stomach in normal time from two to two and one half hours, but even after the passage of all food material there was often encountered an outpouring of pure gastric juice for half an hour, one hour, or even several hours. This finding, which was obtained in many cases, is so pronounced and distinct that we call it a "continued digestive secretion" in contradistinction to "hypersecretion" because it occurs in normal symptomless persons. This type we call the hypersecretory type because of the general tendency of the acidity to assume exaggerated proportions.

These represent but two of such curves in which the tendencies described were pronounced and the "continued" secretion was quite prominent. Several cases in which the acidity approached that seen in the isosecretory type likewise showed this phenomenon.

3. The third or "hyposecretory" type is similar to the first but there is usually a slower ascent, slower response to stimuli, and a high point from 40 to 50. Digestion is usually completed in two and one half hours. This is the type least frequently encountered.

A consideration of the curves from the examination of normal persons indicates that there is no normal curve which will hold for all cases.

A distinction should be made of terms "secretory" refers to the quantity of secretion, "acidity" to the quality or acid grade of the secretion. "Hypersecretion" means the individual who responds to

every stimulus with an abundant secretion, "hyperacidity" whose response although possibly not excessive is still of a high acid grade. However it is found that those individuals with excessive quantity compared to a normal mean usually show also hyperacid compared to a normal mean which one might call the "isoacid" figure.

In other words after studying the average collective response of all normal individuals it becomes apparent that while the motor function in perfect health varies within very narrow limits, the quantity and quality of the secretion has considerable variations. There is a group by no means small in which the secretion is very abundant, the acid figure high, and there is often present a post-digestive or continued secretion. These people always react in this way while there is a group diametrically opposed who show a rather tardive secretory response. Both are normal: both without symptoms: both must be considered in the analysis of any pathological case.

Careful study as far as I can ascertain seems to demonstrate that hypersecretory individuals give hypersecretory responses to all forms of gastric stimuli. Whether it be bread, bread and tea, meat, milk or a mixed meal—our "hypersecretory" students give always an hypersecretory response—and our hypersecretory normal type give as a rule with any form of stimulus a low or a so-called hyposecretory response. In the many experiments numbering several thousand we have been able to predict almost always the type of response which a certain individual would give after trying him out with a certain substance. Of course there are daily variations and extreme fatigue as well as gastric abuse will entirely change the gastric output as we have been able to demonstrate.

These findings are extremely important because they must make us cautious in drawing unwarranted diagnostic conclusions on the quantity and quality of the secretion. In over 40 per cent. of our cases, we found figures exceeding 60 total acidity and it is perfectly apparent that the diagnosis of pathological hyperacidity for figures exceeding 60 must be entirely rewritten when it is evident that this occurs at some phase in the digestive cycle of many normal individuals.

Over 30 per cent. of normal cases develop an acidity in excess of 70 or 0.25 per cent. HCL and the probabilities from our experi-

ments are that the perfectly pure secretion varies between 0.3–0.4 per cent. of HCL instead of the 0.2 per cent. of clinicians.

An extensive study was made of the psychic secretion and for this purpose healthy students were selected, the stomach evacuated and residuum removed before any food was taken, and the tube left *in situ*. They were then placed in front of a weighed steak, and the secretion from the sight and odor of food recorded by complete interval evacuations, this was followed by the chewing of the meat but no material could be swallowed, all meat being expectorated after a definite time interval of chewing. These experiments, the first ever performed on healthy non-traumatized human subjects, and as yet unpublished, are full of interesting data. In 33 separate observations on about 12 subjects, the following points were recorded:

(a) There is a definite psychic secretion varying in duration of from 60–80 minutes, perhaps longer if the psychic stimulus is continued.

(b) There is no latent period as Pavlov indicated.

(c) The amount of secretion in the series without atropine varied in 14 pure psychic cases from 105 c.c. to 274 c.c. with an average of 122 c.c. during the period. After the oral or hypodermic administration of atropine, which presumably cuts out the psychic responses, in 12 cases the quantity removed varied from 15.5 c.c. to 64 c.c., with an average of 37.6 c.c., a difference of 85.4 c.c. on the average or in other words of 69.2 per cent. (more than two thirds).

(d) There is evidence to believe that the chemical secretion is induced at a very early period, and probably occurs well in the first hour.

(e) In 12 out of 21 straight experiments without atropine the acidity exceeded a total acid of 70 varying from 74 to 114.5 T. A. 0.41 HCL with an average of 97.3 c.c. indicating in over one half the normal psychic responses give an acidity in excess of 70 while the average is equal to or above this point. This finding is supplemented by the fact that in 14 out of the 21 cases the free acid exceeded 50, the figure frequently given for normal total acidity. These findings in themselves throw an entirely different light on the

whole subject of pathological gastric chemistry. In only two instances out of 12 atropine experiments did the total acidity exceed 70 (16.6 per cent.) and they were 79.5 and 71.5 respectively, while in four of those cases (33 per cent.) the free acid exceeded 50. In other words, it was possible to demonstrate directly a definite reduction both in the quantity and in the acidity of the psychic secretion after the administration of atropine.

(f) On a pathological case (ulcer) we were able to demonstrate a marked increase in the quantity of the psychic secretion under the same circumstances as well as an increased velocity in the formation of the secretion.

While the psychic response may vary markedly under certain circumstances, the phase which we call chemical late in digestion and which we attribute to secretagogues, hormones, the formation and absorption of certain gastrins, is remarkably constant.

Normally the factor of safety is very great in the stomach, but any pronounced deviation from normal whether due to excessive ingestion of indigestible food, indulgence in alcoholic liquors or to marked fatigue of any kind is usually followed by recognizable gastric disturbances, among which are a tendency to excess of or persistent secretion and frequently minimal food retention due to disturbed motility.

A consideration of the foregoing facts enables us to construct a rational basis for the interpretation of pathological phenomena. In the first place it must be evident that normally the evacuation time is remarkably constant. Abnormally any variation can occur from a marked acceleration of the gastric contents seen in certain forms of achylia and in the accelerated peristalsis of certain forms of duodenal ulcer and duodenal irritation to the delayed evacuation only partial seen in certain forms of atony to the pronounced delays seen in the various forms of pyloric stenosis.

From a secretory standpoint, many things may occur. The evolution may be entirely abnormal. The development of the secretion may be accelerated or retarded, in reality delayed gastric digestion; or there may be at any phase in the gastric cycle the entrance of pronounced secretory perturbations as hypersecretion or the elimination or secretion of a juice of high acid grade. The

reverse, disturbances pointing to insufficient acidity and secretion are found.

While this is not the place to discuss the question of ulcer and cancer, the former has a constant tendency to induce gastric phenomena of the spastic type together with excessive secretion and increased acidity, while the presence of the latter has a definite downward tendency on the secretory causing either an inhibition or neutralization or late formation of the secretion due to a mucosal lesion. Every variety of change in the specimens can occur from positive disturbance in the quantity and quality of the secretion to the admixture of purely pathological exudates or transudates consisting of blood, pus, bacteria which are more or less characteristic of certain conditions as well as definite fermentative phenomena seen in certain forms of stasis. A recognition of the normal type and its thorough understanding is essential to the interpretation of the pathological responses which occur.

THE COMMON FOLK OF SHAKESPEARE.

By FELIX E. SCHELLING, A.M., LL.D.

(Read April 13, 1916.)

"Shakespeare . . . seems to me," says Walt Whitman, "of astral genius, first class, entirely fit for feudalism. His contributions, especially to the literature of the passions, are immense, forever dear to humanity—and his name is always to be revered in America. But there is much in him ever offensive to democracy. He is not only the tally of feudalism, but I should say Shakespeare is incarnated, uncompromising feudalism in literature."

With such an arraignment of Shakespeare's universality and his sympathy with his fellow men, let us consider the common folk of his plays with a view to discover the poet's actual attitude towards that humbler station in life into which he was himself indisputably born. For our purpose we exclude all personages of rank, all his characters of gentle birth, together with all those, whatever their varying degrees of servitude who wait upon royalty or form in any wise a part or parcel of the households of great folk. This excludes all of Shakespeare's heroes. It will also exclude Shakespeare's fools, from trifling Launce and the delectable Feste to the sad-eyed companion in folly of King Lear. And even Falstaff, who was sometime page to Sir Thomas Mowbray and a gentleman, however unlanded, must stand in his dignity without our bounds.

There remain for us, in our middle domain, some three or four score personages who have speaking parts, of a diversity the equal of their betters and inferiors, even although their actual rôles are, for the most part, subordinate. Conveniently to treat so many of the undistinguished, we must group them, a process the more justifiable when we consider that thus we can best ascertain, what are really Shakespeare's prejudices and whether they are of class or individual.

The drama by Shakespeare's day had already evolved, or rather created by iteration, several very definite stock personages. One of these is the pedant or schoolmaster, so well known to Italian comedy; and Holofernes, in "Love's Labour's Lost," with his loquacity, affectation of learning and essential ignorance, is Shakespeare's most certain contribution to the type. As to "the pedant" so nominated in "The Shrew," this personage is taken over bodily from Gascoigne's "Supposes," the translation of an Italian play, and performs no "pedantic" function; while Pinch, in "The Errors," is called in momentarily to exorcise the devil out of half maddened Antipholus of Ephesus. In the Welshman, Sir Hugh Evans of "The Merry Wives of Windsor," we modulate, so to speak, from the schoolmaster to the parson, for Evans apparently performed the functions of both. Evans is no fool, however he may have sung to keep up his courage on one memorable occasion, in breaking voice, ungowned and sword in trembling hand, while he awaited the coming of his terrible adversary, the French Doctor Caius, deceived in the meeting like himself, by a parcel of incorrigible wags.

Shakespeare's curates, parsons and religious folk are many. Of the class of Evans are Sir Nathaniel, in "Love's Labour's Lost" and Sir Oliver Martext in "As You Like It." Sir Nathaniel is zany to the ponderous folly of Holofernes, he who plays the rôle of "Alisander" to the latter's Judas in the immortal "ostentation, or show, or pageant, or antique of the Niñe Worthies"; while our joy in Sir Oliver lies more in his delectable cognomen "Martext" than in the very brief scenes in which he is brought in to "despatch" Touchstone and his Audrey into matrimony under the greenwood tree. The Shakespearean friar is a more important personage, from the plotting, necromantic Home and Southwell in the second part of "Henry VI" to Juliet's Friar Lawrence with his minor counterpart of minor function, Friar Francis in "Much Ado," and the Duke, disguised as such, in "Measure for Measure." Whether a matter wholly referable to his sources or not, Shakespeare conceived of the friar of Roman Catholic Verona, Messina or Vienna, in a very different spirit from that in which he represents the small parson, Sir Hugh or Sir Oliver. Friar Francis in "Much Ado" detects the "strange misprision in the two princes" whereby the Lady Hero

is slanderously wronged, and it is his prudent advice, which, followed implicitly by the lady and her friends, rights that wrong in the end. The likeness of this function of Friar Lawrence is patent to the most superficial reader; but unhappily for his prudence and his ingenuity, the accident to his messenger, the precipitancy of Romeo, the influence of the very stars is against him and he fails where his brother friar had succeeded. Nowhere in Shakespeare does the clergy function with more dignity than in "Measure for Measure" whether in the rôle of the chaste and devoted novice, Isabella, or in the grave and searching wisdom of the Duke. What Shakespeare's attitude toward formal religion may have been we have little that is definite to go by. Who can doubt that it was he, however, and none other, who paid for the tolling of the great bell of St. Saviours when his brother's body was laid there to rest? And who can question with all his scenes of religious pomp and dignity that Shakespeare recognized, with Wolsey, that all these forms of earthly vanity are

a burden

Too heavy for a man that hopes for heaven?

We may regret that Shakespeare has nowhere exhibited to us, like Chaucer in his "poure Persoun of a toun," his ideal of the cloth. It has been wittily said that it is a credit to human nature that no critic has as yet called Shakespeare a Puritan. It is somewhat less creditable that some have gone about to show him the satirist of Puritanism, especially in Malvolio. It was Jonson, the moralist, who satirized Puritanism, not Shakespeare, whose business was with qualities that differentiate men in the essentials of their natures and in the conduct which these differences entail.

Let us glance next at the physicians of Shakespeare. In Dr. Caius of "The Merry Wives," albeit he is boastful of his intelligence from the court, the doctor is lost in the gross wit of the Frenchman's ignorance of English satirized. The apothecary who sells Romeo his death potion, in his "tattered weeds," could assuredly not have been of a profession in which there are no beggars. The father of Helena in "All's Well," although he left to his daughter the miraculous cure of the King of France by means of his medical secrets,

is reported a man of dignity, learning and much experience in his practice. The doctor in *Macbeth* has won the praises of his own jealous profession with the professional aptitude of his comments on the somnambulist symptoms of Lady Macbeth; while the physician, Cornelius, skilled as he is in poisons, honorably deceives the wicked queen of *Cymbeline* with a sleeping potion instead of the deadly drug which it was her purpose to administer to the unhappy Imogen.

Unlike his contemporary Middleton and some others, Shakespeare does not satirize the profession of the law; and the lawyer, as such, scarcely figures in the plays. At opposite poles, in the plays which have to do with Falstaff, we have Master Shallow "in the county of Gloucester, justice of the peace and 'coram,'" described by Falstaff as "a man made after supper of a cheese-paring . . . for all the world like a forked radish, with a head fantastically carved upon it with a knife." And we have likewise the grave and honorable Chief Justice Gascoigne, whose courage and impartiality in the exercise of his high functions caused the regenerate Prince to choose him for his guide and counsellor on the assumption of his new royal dignities. As to the lesser functionaries of the law, the watchman, the constable and the beadle, Shakespeare exhibits the general free spirit of his time and laughs, as the rest of the world has ever laughed, at the insolence, ineptitude and ignorance of the small man dressed in a little brief authority. It might be argued with some likelihood of success that this is identically the spirit that marks the Sheriff of Nottingham as the butt of the lawless pranks of Robin Hood, the attitude towards constituted authority which combined in the free ranging devils of the old miracle plays the functions of policing the crowd and catering to its merriment. Beyond his designation, "a constable," Dull in "*Love's Labour's Lost*," scarcely represents for his class more than his name; and as to Elbow in "*Measure for Measure*," his "simplicity" like his malapropisms, seems a faint and colorless repetition of these qualities in the immortal Dogberry. Dogberry is universal, the ubiquitous, inevitable, unescapable man of weight, ponderous alike physically and mentally; for I am persuaded with an old-fashioned American critic, that Dogberry was "of ample size—no small man speaks with sedate

gravity. . . . No man of the lean and dwarfish species can assume the tranquil self-consequence of Dogberry. How could a thinly covered soul [exhibit] . . . that calm interior glow, that warm sense, too, of outward security, which so firmly speaks in Dogberry's content and confidence."¹

Our obvious generalization as to Shakespeare's estimate of the learned professions, then, is this: he found, in all, earnest, honorable and capable men and honored them as such; and he found likewise among them the stupid, the pedantic, the pretentious and the absurd. It was for their follies that he ridiculed them, not because of their class or their station in life.

Of the small gentry of Elizabethan England, Master Ford and Master Page with their two merry wives offer us the best example in comedy. The discordant plans and plots for a provision in life for Mistress Anne Page are in keeping with many a like unconscious parody on the grand alliances of folk of higher station. The foolish Slender, who is likewise a small landed proprietor, is nearer an absolute fool or "natural" than any of Shakespeare's clowns, professional or other, for wit proceeds no more out of him, however he beget wit in others, than it ever comes forth from the mouth of Andrew Aguecheek his cousin-german (so to speak) of Illyria. In Alexander Iden, who meeting with Jack Cade in his Kentish garden, kills him in single fight, we have a serious personage of much Slender's station in life. But Iden has his wits as well as his valor about him and his knighting is his deserved reward. Nearer the soil, if closer to royalty, is the kind-hearted, allegorical minded king's gardener who apprises the queen of Richard II. of the monarch's mischance in falling into the hands of his enemy, victorious Bolingbroke. In the country folk that fill in the background of "As You Like It" and the later acts of "The Winter's Tale," Shakespeare's English spirit comes into contact with the conventional types of Italian pastoral drama. Corin is the typical shepherdess, beloved but not loving, and Sylvius, the pursuing shepherd unbeloved. But as if to correct an impression so artificial, we have, beside them, William and Audrey, English country folk in name and nature like Costard and Jaquenetta, and in Shakespeare's

¹ Henry Giles, "Human Nature in Shakespeare," 1868.

maturer art, far more redolent of the soil. William, like Slender, and many a man of better station, is a mere natural; but his witlessness is as distinguishable from the folly of the Shakespearean "clown," as his boorishness differs from the literal simplicity of the Shepherd who becomes foster brother to Perdita in "The Winter's Tale." Mopsa and Dorcas with their shepherds of the sheep shearing, in these charming comedy scenes, are English country folk; and Autolycus, despite his fine Greek name, is a delightful English rogue and incorrigible vagabond.

And now that we have all but touched the bottom of the Shakespearean social scale, we may note that in Shakespeare poverty does not necessarily make a man vicious; nor does roguery destroy humor in a man or deprive him of his brains. The porter in Macbeth is a foul-mouthed drunken lout; the nameless "old man" in the same tragedy is a credulous recorder of marvels. But Adam, the old serving man of Orlando, is faithful almost to death. Dame Quickly of London is a silly old muddlehead, alike innocent of morals and of common sense; and her sister Dame Quickly of Windsor is a shameless go-between and meddler; but the widow, keeper of lodgings for pilgrims in "All's Well," has a virtuous and honorable disposition. The drawer, Francis, in "Henry IV." "sums up his eloquence in the parcel of a reckoning"; but there is no keener, droller fellow in the world than the grave digger in "Hamlet," and it is dubious if for natural parts, however diverted to the "doing" and undoing of his fellows, Autolycus has ever had his equal. Shakespeare's carriers talk of their jades and their packs; his vintners and drawers of their guests and their drinking; his musicians disparage their own skill and have to be coaxed to show it; and his honest botchers, weavers and bricklayers hate learning, and in their rage variously kill a poet and hang a clerk. And curious as all this may appear to him who habitually views the classes below him as merely his servants or the objects of his organized charity, all this—save possibly the homicides—is as true of today as of the age of Shakespeare.

And here perhaps as well as anywhere, we may digress into "the Shakespearean prejudice as to mobs." The mob figures as such conspicuously three times in Shakespeare's plays, in the second part of "King Henry VI.," in "Julius Cæsar," and in "Coriolanus." It

is represented in all three cases as fickle, turbulent, cruel, foul and possessed of a rude sense of humor; and this last is Shakespeare's—perhaps, more accurately, the Elizabethan—contribution to the picture. It has been well observed that Tudor England presented no precise parallel to the persistent struggle of the Roman plebs against the bulwarks of patrician oligarchy. And it is doubtful if Shakespeare would have sought for such parallels had they existed. In unessentials—and the picture of the mob is such to the dramatic action of these two Roman plays—Shakespeare is always faithful to his sources, and Plutarch's crowd is cruel, seditious, and "contemptibly responsive" to the most obvious blandishments of the demagogue. In the admirable scenes of Jack Cade's rebellion, although the material was nearer home, Shakespeare once more followed his sources, here in Holinshed and Halle. Neither of these worthies comprehended in the slightest degree the actual political issues underlying the Kentishmen's revolt, which historically was as respectable as it was fruitless. But Shakespeare was not seeking historical accuracy, but dramatic effectiveness and fidelity to the observed characteristics of ignorant men escaped from the curb of the law. Shakespeare, as to the mob, was no sociologist, and his yearning for the submerged tenth was not that of many a worthy gentleman of our own time who otherwise misrepresents the unshriven objects of his solicitude. In short a mob was to the unlettered dramatist merely a mob. Man running in packs unbridled by authority was a phenomenon better known to unpoliced Elizabethan England than to us, and Shakespeare found most of his own impressions in this matter to tally remarkably with those of Plutarch and Holinshed.

With Shakespeare's mob we leave the country and meet with the small tradesmen of towns; for even the Kentish "rabblement" of Jack Cade is represented, like that of ancient Rome, as made up of small trades people—cobblers, butchers, smiths and the like—not folk of the fields. Individually as collectively, Shakespeare has a greater appreciation for the humors of the tailor, the joiner, and the bellows-mender than for his psychology. The drunken tinker of "The Shrew" the author found in his source and, unlike that source, wearied, he dropped his adventures when the play within the play

was at an end. The hempen homespun with the illustrious weaver, Bottom, at their head, repeat in their absurd drama of "Pyramus and Thisbe," a situation already sketched in "Love's Labour's Lost," one in which the banter and cruel interruption of ungentle gentles evidently reproduces a situation by no means unknown to better actors than Bottom, Flute and Starveling. A kindly spirit speaks in the words of Theseus:

For never anything can be amiss
When simpleness and duty tender it;

for truly is he tolerant who can find words of praise for the good intentions of the amateur actor, a being little loved of god or man. To the professional player, whom he knew better than any other man of art, Shakespeare is courteous and appreciative in the person of Hamlet, and we know from an often quoted sonnet, how deeply he could feel the degradation which popular contemporary opinion attached to the player's art.

The merchant, in Shakespeare's day, was a far more dignified person than the mere man of trade. A merchant, it is true, waits with a jeweller, but also with a painter and a poet, in the anteroom of silly, sumptuous Timon. But ordinarily, the merchant is a more dignified person, extending courtesy to strangers, as in "The Comedy of Errors," taking risks for his merchandise and for himself, as in the case of old Ægeon, in the same play, who has ventured on markets forbidden and is imprisoned for his daring. The most notable Shakespearean merchant is, of course, Antonio, the merchant prince of Venice, an adventurer in the Elizabethan sense into strange markets and a gambler for high commercial stakes. His gravity—or presaging melancholy—befits his dignity, and his generosity to Bassanio, a fellow adventurer (but in more than the Elizabethan sense), is only equalled by his authority among his fellow merchants and his scorn of the unrighteous Jew. Shylock, too, is of the merchant class, but a pariah alike for his race and his practice of usury. But Shylock will take us into precincts irrelevant; for the Jew, whatever your thought of him or mine, is not of the common folk even of Shakespeare.

Next to the merchants come Shakespeare's seamen, the noble-minded Antonio of "Twelfth Night," Sebastian's friend, the outspoken sea-captain, boatswain and mariners of "The Tempest," the attendant sailors and fisher folk of "Pericles." Shakespeare was a landman; save for an occasional line, his descriptions of the sea, in the richest of all literatures in this respect, are none of them important. The mariner as such he treats with the respect due a person only partially known. With the soldier, in a martial age, Shakespeare was better acquainted and he knew him from the kings and great commanders of the historical plays to such pasteboard and plaster military men as Parolles, Nym and Pistol. Of Falstaff's levy and his rabble attendants, from Bardolph of the carbuncled nose to the minute page, it may be said that they cut a sorrier figure in France than at the Boarshead in Eastcheap. But Shakespeare's army levied better men than these; the heroic gunners on the walls of Orleans, the brave and capable captains of four kingdoms, Gower, Fluellen, MacMorris, and Jamey in "Henry V.," and the manly English soldiers Bates, Court and Williams. If the refined, modern critic, versed in the psychological researches of an incessantly prying world, would learn whether the old dramatist, Shakespeare, had any notions as to the mental processes and moral stability of the common man, let him read and ponder the simple incident of King Henry V. incognito, and the soldier Williams and their arguments pro and con as to the responsibility of princes. Williams is the type of the honest, fearless, clear-headed "man in the street" who honors his king, not slavishly because he is a king, but for the qualities that make him kingly, who respects manhood (his own included) above rank and is the more valiant that he knows the cost of valor. There are several well-known tales of military devotion—they are not English—of the soldier, wounded unto death in a quarrel, the righteousness or wrong of which he cares not even to inquire, who dies blessed and content that he has obeyed in unquestioning faith, the august commands of his master. Williams is not of this type. His free soul will challenge his gage in the eye of his prince and when his heart tells him he is right, let the devil forbid. Shakespeare, too, knew the common man, who is bleeding today for England; and his trust, like ours, was in him. Nor did our wise old dramatist,

for all his scenes of the pomp and circumstance of war, forget its terror, its sorrow and its pathos. In the third part of "Henry VI.," that unhappy king is seated alone on the field of battle as the struggle surges away from him. And there enters "a son that hath killed his father dragging in the dead body," and later "a father bearing his dead son." Poignant are the words of these common men in their common woe, the battle woe of all ages and all times in the grip of which the least are as the great and the greatest as the poorest.

In the taverns, the brothels and the jails, Shakespeare found the foulmouthed, the ignorant and the dishonest and he represented them in all these particulars in a faithful, if at times, forbidding, reality to life. Moreover, his prejudice against evil is pronounced in the very repulsiveness of such scenes. He knows that there are impostors among beggars, that trial by combat is only a somewhat cruder method of getting at the truth than trial by jury, that there are corrupt and incompetent magistrates and fools abounding in all walks of life. Moreover, he depicts in his plays a feudal state of society, for such was English society in his day. But there is nothing in these honest dramatic pictures of English life, from the king on his throne to Abhorson with his headsman's axe, to declare Shakespeare prejudiced against any class of his fellow countrymen. Wherefore, our obvious generalization as to Shakespeare's attitude toward common folk, whether they be learned or unlearned, is this: he found among them the stupid, the ignorant, the pretentious and the absurd; but he found likewise in each class the earnest, the honorable and capable, and honored each after his kind as such. For their follies he ridiculed them; for their virtues which he recognized, he loved them, deflecting neither to ridicule nor respect because of station in life.

THE ORIGIN AND VEGETATION OF SALT MARSH POOLS.

(PLATES IX-XIV.)

By JOHN W. HARSHBERGER, PH.D.

(Read April 14, 1916.)

The natural, undisturbed surface of the salt marshes of our eastern Atlantic coast is fairly uniform in character (Plate IX., Fig. 1) from Cape Cod south, as far as the mouth of Chesapeake Bay. They are formed at the mouths of rivers, which empty into the ocean, and behind the barrier islands of sand, which fringe the coast, in the quiet waters of the lagoons which become fringed with salt marshes of varying width (Plate IX., Fig. 2), or the open lagoons, or bays, are completely invaded and converted into a salt marsh of fairly large size. The tidal channels, or thoroughfares, as they are called in New Jersey, still permit the entrance of sea water and the surface of the marsh is partly, or wholly, flooded with water depending upon the state of the tide.

The outer margin of the salt marsh where it touches the open lagoon (Plate IX., Fig. 2), or the tidal thoroughfare, is fringed with a broader, or a narrower strip of the tall salt grass, *Spartina glabra* (Plate X., Fig. 1), depending upon the level and slope of the marsh surface. Back of this strip, or association, we find the rush salt grass, *Spartina patens*, which grows at a slightly higher tidal level, and is of varying width and outline, and then come the extensive areas of the black grass, *Juncus Gerardi*, upon which the economic value of the marsh depends. Sometimes there are extensive areas covered with the lesser salt grass, *Distichlis spicata*. The samphire, *Salicornia europæa*, grows sometimes in pure association, sometimes mingles with *Spartina patens* and *Distichlis spicata*, while the sea-lavender, *Limonium carolinianum*, also grows in association with the grasses and samphire in places over the surface of the marsh, as also *Suaeda maritima* and *Atriplex patula*. Where fresh-water con-

ditions begin to prevail, that is along the inner tension line of the salt marshes, we find *Hibiscus moscheutos*, *Baccharis halimifolia* and *Iva frutescens* along with *Ptilimnium capillaceum*, *Cicuta maculata*, *Myrica carolinensis* and other plants, either in front of, or in the center of the thicket vegetation.

The surface conditions, which we have described above, may be disturbed by the action of strong eddying currents of wind, which blow across the salt marsh. The grasses and other marsh species are blown down and become matted and twisted, so that marsh surface has a billowy appearance (Plate X., Fig. 2) with extensive areas of erect marsh plants, and depressed portions of greater or less size of prostrated grasses. With exceptionally high tides, which carry the dead stems, leaves, and other remains of the marsh plants about with them, the floating material is carried in over the marsh and deposited upon the surface of the salt marsh plants, especially in the hollows of the grassy surface, which have been caused by the wind (Plate X., Fig. 2, and Plate XI., Fig. 1). These rafts of vegetable debris are left on the surface of the marsh with the tidal retreat, and as the water level may not rise again to a similar level for several days, or even months, the drift material smothers the growing plants beneath it, and rapid decay sets in. This smothering action may be effective in larger or smaller areas of the marsh (Plate XI., Fig. 1), and the tops of the plants are not only destroyed, but the decay reaches the underground parts as well. Not only are the underground parts destroyed, but also the surface of the salt marsh sod, which is above the permanent ground water level. Depressions in the salt marsh are thus formed, which vary in size from a few feet across to areas an acre or more in extent. These depressions usually have steep sides and become filled with water at high tides, and thus constitute the typic salt marsh pools (Plate XI., Fig. 2; Plate XII., Fig. 1) which are in evidence in every salt marsh along the Atlantic coast.

Various algæ begin to grow in these quiet pools (Plate XI., Fig. 2), and an investigation of the algæ found in such pools at Cold Spring Harbor, Long Island, showed the presence of the following blue green algæ: *Lyngbya semiplena*, *Microcoleus chthonoplastes*, *Oscillatoria limosa*, *Riccardia atra* and such diatoms as

Pleurosigma angulatum, *Melosira nummuloides* and a species of *Navicula* and *Synedra*. With the retreat of the water and the drying up of the pools, these algæ and diatoms form crusts, or matted masses (Plate XII., Fig. 2), mixed with the dried leaves of *Zostera marina* and the remains of other plants. In one pool pieces of newspaper were found stuck together by the mat of blue green algæ. The mats of partially dry algæ and diatoms (algal paper) assist in the further disintegration of the peaty surface of the pool bottom, but a limit is reached beyond which the process of decay is checked. With a change in drainage of the salt marsh, some of the pools are only occasionally filled with salt water, and the algæ begin to die and disappear, leaving a barren soil, which in very dry weather may sun crack, as shown in the photograph of such a pool in the salt marsh back of Atlantic City, New Jersey (Plate XIII., Fig. 1). Such denuded areas are now invaded by typical salt marsh species. One such pool investigated was tenanted by a pioneer plant, *Atriplex patula*, while an old crescent-shaped depression was completely invaded by *Triglochin maritimum* in pure association, and another area with *Pluchea camphorata*, *Plantago maritima* *Solidago sempervirens*. Still another bare area was invaded by *Spergularia marina*, *Plantago maritima* and a few weak plants of *Solidago sempervirens*.

An extensive area completely denuded of vegetation by the smothering action of drift material and completely riddled with the burrows of the fiddler crabs, *Gelasimus pugnax* (Plate XIV., Fig. 1), was found occupied by a pure association of the samphire, *Salicornia europæa*, which is frequently the pioneer species on such mud flats (Plate XIII., Fig. 2). Not all of the areas in our eastern salt marshes are due to the smothering action of the drift material, which consists largely of the dried remains of *Spartina glabra* and *Zostera marina*, but occasionally, we find a sloping gravel bank, as at Cold Spring Harbor, Long Island, where a fresh-water spring controls during a large part of the day the soil conditions, and where the gravel soil is so hard as to preclude the growth of the usual salt marsh species (Plate XIV., Fig. 2). Under such conditions *Lilæopsis lineata* grows. It is an interesting little umbelliferous plant with fleshy spatulate leaves, a running stem, and a

small umbel of white flowers. During part of the day it is exposed to submergence by salt water and during the rest of the day, its leaves are subjected to the action of air and sunlight, while its roots and creeping stems are influenced by fresh water. Such a plant must change its osmotic relations several times a day, alternately being exposed to the action of salt and fresh water. It was under such conditions of environment that the plant was first detected in New Jersey by Thomas Nuttall, who found it near "Egg Harbor," apparently near Beesley's Point.

Soon the typic salt marsh species such as *Spartina glabra*, *S. patens*, *Distichlis spicata*, *Juncus Gerardi* gain access to the barren ground occupied by the pioneer species (Plate XIII., Fig. 2; Plate XIV., Fig. 1), which are gradually replaced by the plants which are dominant in the salt marsh. After these vicissitudes of salt marsh existence, we find the climax vegetation restored, and the areas formerly denuded by the smothering action of drift material and algæ appear again, and the usual flat, featureless, meadow-like physiognomy of the salt marsh surface appears again (Plate IX., Fig. 1). In the study of the origin of salt marsh pools, we have traced the successional history of plants which are normal constituents of the salt marsh flora, but which become associated together in a different way upon the genesis of the pools of larger and smaller size, which are typic features of the meadow-like expanses of our eastern Atlantic halophytic marshes. As the genesis of the pools with their algæ and other species of flowering plants are due directly to the action of the tides in carrying the flotsam and jetsam of salt plants over the surface of the marsh, so with the elevation of the marsh, and the absence of the daily or periodic flooding of the surface with sea water, we find a cessation in the formation of tidal pool formation and the permanence of a level, uniform surface of salt marsh, which may later change its physiognomy and floral character, when fresh-water conditions come to prevail. The ecologic succession of such converted areas of salt marshes is an entirely different problem, but its essential features have been described previously in a paper¹ entitled "The Reclamation and Cultivation of Salt Marshes and Deserts."

¹ Harshberger, John W., *Bulletin of the Geographical Society of Philadelphia*, July, 1907.



FIG. 1. General view of meadow-like surface of salt marsh at Cold Spring Harbor, Long Island, looking north toward Harbor, July, 1913. The area of the middle ground is occupied by an association of *Juncus Gerardi*.



FIG. 2. Lagoon and fringing salt marsh back of Atlantic City, New Jersey, June 23, 1914.



FIG. 1. Tall salt grass, *Spartina glabra*, fringing salt marsh at Cold Spring Harbor, Long Island, August, 1914.



FIG. 2. Surface of salt marsh at Nantucket, Massachusetts, billowed by the wind, August, 1914.



FIG. 1. Billowed surface of salt marsh at Cold Spring Harbor covered with drift material which smothers the other plants, July, 1914.



FIG. 2. Salt marsh pool back of Atlantic City, New Jersey, June 23, 1914. The algae will be noted growing in the upper right side of the pool.



FIG. 1. Salt marsh pool at Nantucket, Massachusetts, August, 1914, surrounded in part by tall salt grass, *Spartina glabra*.



FIG. 2. Dry salt marsh pool at Cold Spring Harbor, Long Island, with dry crusts of algae, July, 1914.



FIG. 1. Dry salt marsh pool back of Atlantic City, New Jersey, showing mud cracked with sun cracks, June 23, 1914.



FIG. 2. Denuded area in salt marsh at Atlantic City, New Jersey, re-invaded by samphire, *Salicornia europaea*, June 23, 1914.



FIG. 1. Denuded area in salt marsh at Cold Spring Harbor, Long Island, riddled by burrows of fiddler crabs and reinvaded by pioneer vegetation of samphire, July, 1914.



FIG. 2. Gravelly area at inner margin of salt marsh at Cold Spring Harbor, Long Island, July, 1914, controlled during low tide by fresh water and occupied by *Lilaeopsis lineata*, which is submerged at high tide.

PATHOLOGICAL ANATOMY OF THE INJECTED TRUNKS OF CHESTNUT TREES.

(PLATES XV-XVIII.)

BY CAROLINE RUMBOLD, PH.D., DR. OEC. PUBL.

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While working on tree injection in connection with the chestnut-tree blight, a large number of Paragon chestnut trees (orchard trees) were made the subjects of experimentation by introducing into their trunks different substances in solutions of varying dilution. The method used in making the injections has been described in *Phytopathology* (1).

The injections were made to discover the effect of the chemicals on the chestnut trees and in turn on the parasitic fungus *Endothia parasitica* (Mur.) A. & A., the cause of the chestnut-tree blight. The reason for undertaking these experiments is mentioned, because the processes devised for this investigation not discussed in this paper, have rendered the phase of results here presented, somewhat uneven and unfinished. Further study on this subject is in progress.

The chemicals used in the injections were about 50 in number: hydrocarbons, metals and alkali metals. So far an examination of the trunks and branches of injected trees shows that their reactions to the different chemicals were alike in kind but varied in intensity. The effect of the chemicals on the leaves of the trees differed, but this will not be discussed at this time.

The injected solution passed through the vessels of the youngest and the one year old rings of wood. There were exceptions to this rule, which will be explained later.

The reaction in the trunk and branches of the tree varied with the distance from the point of injection. The affected region extended up and down the trunk in a line whose width usually was but little more than the injection hole. The cells through which the

solution passed acted like a blotter, with the result that the farther from the point of injection, the more dilute was the solution and the smaller the injected stream. Correlated with this, the tree tissues appeared more normal as the distance from a point of injection increased and the area of disturbance decreased. Occasionally all stages of reaction to an injection could be seen in a tree: death—at the point of injection—retarded growth, stimulated growth and no reaction.

The results of the injections, to which particular attention is called here, are of interest from a histological standpoint.

1. A strong inhibitory effect on the growth of the cambium layer was noticed; so strong that as a tissue it often disappeared. The cambium cells changed into xylem.

2. There was an irregular formation of the new year ring of wood. During its formation isolated groups of xylem cells appeared in the midst of the phloëm.

3. Phloëm cells were converted into xylem by cell division followed by lignification, or the cell walls were lignified without cell division.

4. All of the cells of the phloëm region were capable of change with the exception of the stone cells, the bast-fibers and their accompanying cells containing crystals.

5. There was a production of wound tissue showing various degrees of abnormality. The wound tissue was abnormal in that its position was reversed from the one in which it is customarily seen, and frequently the cells composing it had unusual shapes.

6. Cork formed prematurely. It was apparently correlated with the irregular growth of xylem in the phloëm region.

Another region of response to the injections was the xylem, evidenced by an increased formation of thylloses and a thickening of cell walls. This response, while pathological, was one which was expected. For this reason no emphasis is placed upon it in this discussion, but it will be referred to in connection with the paths of the injected solutions.

These points can be elucidated best by a view of some sections cut from injected trees. They have been selected from many, as they illustrated the points emphasized in this paper.

OBSERVATIONS.

The Path of the Injected Solutions in the Trees.

As stated before, the path of the solutions usually was through the vessels of the youngest ring of wood (Figs. 2, 5, 10, and 11). It sometimes happened that the stream was shifted from these vessels. Fig. 1 shows such a case. This section was cut from a tree which had been injected with methylene blue. The stain had colored the passages taken by it. The solution of methylene blue was not toxic, but it was stimulating enough to cause the formation of thylloses, which finally plugged the vessels through which the stain passed. The main stream then passed through the vessels of the older year ring. The amount of such shifting appeared to vary with the toxicity of the injected chemical, for killing solutions never changed their paths (Fig. 2). This shifting by removing the source of irritation that is the injected solution from, or bringing it in closer proximity to, the cambium layer had a decided effect on the growth of the cambium and phloem tissues.

THE WOUND TISSUE FORMED.

The character of the wound tissue depended on the toxicity of the injected solution. Quick killing was not followed by stimulation other than the formation of normal wound tissue (callus) to cover the wound. Fig. 2 shows an instance of this. The section was cut from a branch of a 9-year-old tree, which had been injected in May with meta cresol 1-1000 G.M., the branch having been cut in October. Callus had formed on both sides of the path of the injected chemical. The photograph shows one side of this path which could be distinguished readily by a stain (*s*). The callus which had formed is as normal as though the tree had been cut by a knife; the wound cambium or bark cambium (*bc*) surrounds the newly formed tissues; the groups of bast-fiber (*bf*), the protective cells, have the formation one sees in a one-year-old twig; the phloem (*p*), cambium layer (*c*) and xylem (*x*) are normal.

There are transitions from such normal wound tissue as that just described, which are caused by the varying toxicity of the injected

chemicals. They exhibit more and more abnormality as wound tissue, until the sections show not wound tissue but stimulated growth of cells.

Fig. 3 shows a wound tissue formation in a ten-year-old tree which had been injected in June and July with nitro phenol-para 1-500 G.M. and felled in November. The path of the main stream is shown on the right-hand side of the photograph. The cells had been killed and a callus had formed which was not as well developed as the callus shown in Fig. 2. On the right-hand side the dark streak in the xylem shows the path of the solution. In this region the solution must have been much diluted as compared with the main stream. Here the phloem, cambium layer (*c*) and year ring of wood are normal, with the exception of the xylem cells in the immediate neighborhood of the path of the solution. Somewhat left of the center a stimulating effect is seen in an abnormally placed group of xylem cells in the midst of the phloem.

Questionable wound tissue is seen in Figs. 4 and 6. The xylem formation can be regarded as irregularly formed year rings of wood. In this case the growth of the rings of wood has been stimulated, for the normal ring of xylem had nearly completed its growth before injection began. Or the extra growth of xylem cells on the far side, as regards the cambium region, of the bast-fiber groups can be regarded as a form of wound tissue (callus). The premature bark, which always appears with the abnormal xylem, can be regarded as part of a wound tissue. Fig. 8 gives a detail showing the suggestive arrangement of the protective cells, stone cells, and bast-fibers, in relation to this extraordinary xylem.

INHIBITORY EFFECT ON THE GROWTH OF THE CAMBIUM.

This was a phenomenon common to the injected trees. Fig. 4 shows a section which had been cut from a sixteen-year-old tree, injected with lithium carbonate 1-500 G.M. in July, August, September and October and felled in November. The section shows the relation between the path of the injected alkali (*s*), the cambium layer region (*c*), the irregular growth of xylem cells (*x*) and the irregular growth of bark cambium (*bc*). Fig. 5 shows the enlarge-

ment of a portion of Fig. 4. In the center of the photograph in the region of the cambium layer are cambium cells which have changed into xylem. It shows also that the phloëm cells are changed into xylem by division and by thickening of the walls. A group of xylem cells has started growth on the far side of a group of bast-fibers. Fig. 6 shows a section from the same tree, in which this situation, exhibited in Fig. 4, is more pronounced. Fig. 7 shows an enlargement of the cambium region (*c*). Here it can be seen that the rows of bast-fibers are surrounded by xylem.

The inhibitory effect on the cambium was transitory. In time a new cambium layer formed, arising from phloëm cells. It separated the irregularly formed xylem from the phloëm. It formed a wavy row of cells, but its growth was normal.

PREMATURE FORMATION OF CORK.

Correlated with the abnormal growth of xylem in the phloëm region was a premature formation of cork. This was formed in so striking a manner that the path of an injected solution could be traced on a tree by the raised lumps of cork extending up and down the tree trunks. This cork formation was not in a continuous ridge of tissue, but appeared in irregularly shaped lumps. So certainly was its formation connected with a disturbance of the cambium and phloëm tissues, that one could tell by a cursory glance at a smooth barked tree at what points the above mentioned tissues were damaged. In the case of the lithium-injected trees, the spectroscope showed the presence of lithium in the cork, showing a connection between the abnormal tissues and the foreign chemical injected into the tree. Fig. 6 shows that the formation of this cork is due to an unusual development of bark cambium from phloëm cells.

XYLEM DEVELOPED FROM PHLOËM TISSUE.

The xylem which had formed by division of the phloëm cells, and often appeared to be a form of wound tissue, has been partially described. Fig. 8 shows the development of such xylem. The group of stone cells partially surrounded by xylem was part of a row of such cells. Rows of stone cells often were found in the

phloëm region in the injected trees. It can be seen that there is a close relation between the protective cells, i. e., stone cells and bast-fibers, and the xylem which is formed by cell-division of phloëm cells. Whether any of these groups of protective cells formed after injection future experiment will show. It seems probable that they did, as according to Moeller (2) such a formation can occur in the normal growth of the chestnut, *Castanea vesca*.

An irregular growth of the year ring of wood is shown in Fig. 9, which is a section cut from a fourteen-year-old tree injected May, June and July with nitro phenol-para 1-1000 G.M. and felled in November. The section shows the year ring of wood only. The formation of xylem on the far side of the bast-fibers is shown in a more pronounced form than in the previously discussed sections. No phloëm cells are in this section except bast-fiber and stone cells. The cells on the near side of the bast-fiber groups have been converted into xylem by a lignification of their walls.

Xylem also was formed by the thickening and lignification of phloëm cells without cell division. The section shown in Fig. 10 was cut from a fourteen-year-old tree, which had been injected in June and July with picric acid 1-1000 G.M. and felled in November. The cells of the dark-stained groups in the phloëm region have lignified cell walls and the shape of phloëm cells. This process of lignification is uninfluenced by the proximity of bast-fiber groups. No vessels are formed. It can be seen that the old phloëm rings are capable of change, for here the nine-year-old ring shows lignified cells. Fig. 11, shows a portion of Fig. 10, enlarged. In Fig. 11, a stone cell has been surrounded by xylem cells of abnormal shapes. The pits in the cell walls can be seen.

DISCUSSION.

The investigations of Schilberszky (3) showed that secondary extra-fascicular vascular bundles could be formed on the outer side of the bast-fiber cells in pea and bean seedlings. He found this new tissue developed by the division of the cells of the starch sheath or endodermis. The starch sheath acted as a cambium layer, producing phloëm cells on its outer side and xylem cells on its inner

side. He produced this result by cutting away a part of the seedlings' stems, when they were actively growing.

Schilberszky's result, obtained by cutting, was produced by the injections, when the solutions were toxic enough to kill or to retard the activities of the fibro-vascular bundles and the cambium layer. But the forms assumed by the deranged tissues, resulting from the injections, were not as definite as those obtained by the knife. This was probably for the reason that the toxic solutions did not usually make definite wounds, but killed only groups of cells or single cells, while other groups were simply retarded in growth or even stimulated. Also the shock from the incision was a single one, while in the case of the injections the source of irritation was present for weeks or months.

As stated before, Schilberszky found the extra-fascicular vascular bundles developed from the starch sheath, which is situated just outside the bast-fiber cells in the case of the pea and bean seedlings. This row of cells produced both phloëm and xylem tissue.

In the case of the injections the result cannot be attributed to the stimulation of a single tissue but rather of three: phloëm, cambium and xylem. So far the examination of the trees has not shown a development of new extra-phloëm cells. The xylem cells found in the phloëm region appear to have been produced by cell division of the phloëm cells followed by lignification, or by a lignification of the original phloëm cell walls. The isolated groups of xylem usually commenced to develop just behind the groups of bast-fiber, and this might indicate that the cells there were meristematic or cells which retained unusual regenerative powers. It has not been known hitherto that they were meristematic cells. It seems more probable from the way in which the groups of xylem cells increase, that these phloëm cells first respond to stimulation because of their position behind the bast-fiber groups. Osmosis in the case of the bast-fibers must be extremely slow. Therefore, an irritant coming from the direction of the injected chemical would strike the cells situated just back of the bast-fibers from two sides at once. Those phloëm cells, exposed directly and from one direction, would respond more slowly by a lignification of their cell walls.

All the cells of the phloëm are capable of change with the exception of the stone cells, the bast-fibers and their accompanying cells containing calcium oxalate crystals. Not only can the cells respond which are in the recently formed rings of phloëm, but those in the rings eight and nine years old. From the phloëm cells are formed bark cambium, cambium and xylem.

SUMMARY.

So far an examination of chestnut trees, injected with chemicals in solution, shows that the reaction in the trunks and branches, as evidenced by abnormal tissues, was alike in kind, but varied in intensity.

With increased distance from a point of injection the tissues became more normal and the area of disturbance decreased. All stages of reaction could be seen in a tree: death, inhibited growth, stimulated growth and no reaction.

The regions of response were the phloëm, cambium, and xylem.

The Phloëm.—The most remarkable response from a histological standpoint, was that given by the phloëm. Xylem cells formed in the midst of the phloëm region. This xylem was formed by division of the phloëm cells with subsequent lignification of the walls, or by lignification of the phloëm cell walls without division. All the cells in the phloëm were capable of change, except the stone cells, the bast-fibers and those cells containing calcium oxalate crystals, which accompany the bast-fibers.

The phloëm cells changed into bark cambium, cambium and xylem cells.

Cork formed prematurely, due to an unusual development of bark cambium in the phloëm region.

The Cambium.—The cambium layer often disappeared. Its cells were changed into xylem.

The Xylem.—The xylem responded by increased formation of thylloses and thickening of cell walls.

Wound Tissue.—Wound tissue formed which varied from normal to abnormal according to the toxicity of the solution injected.

BOTANICAL LABORATORY,
UNIVERSITY OF PENNSYLVANIA,
April 17, 1916.

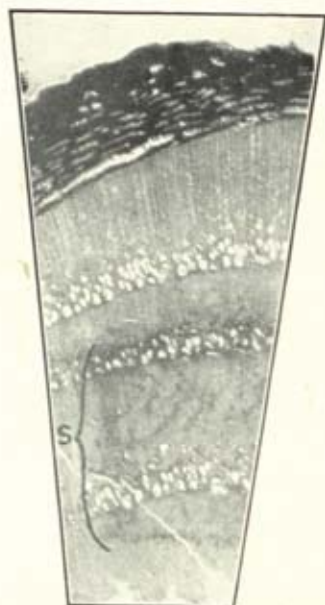


FIG. 1.

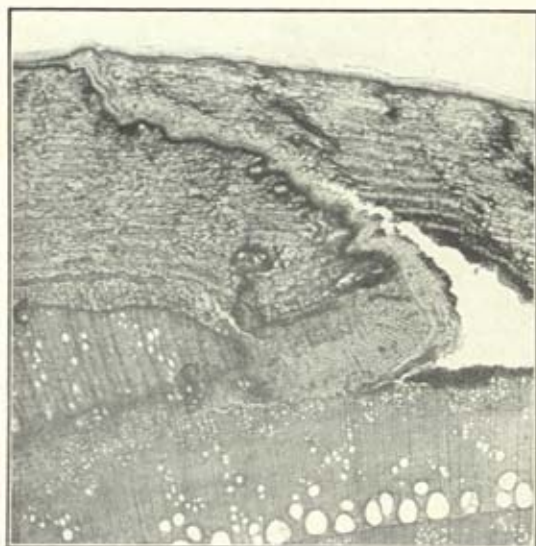


FIG. 3.

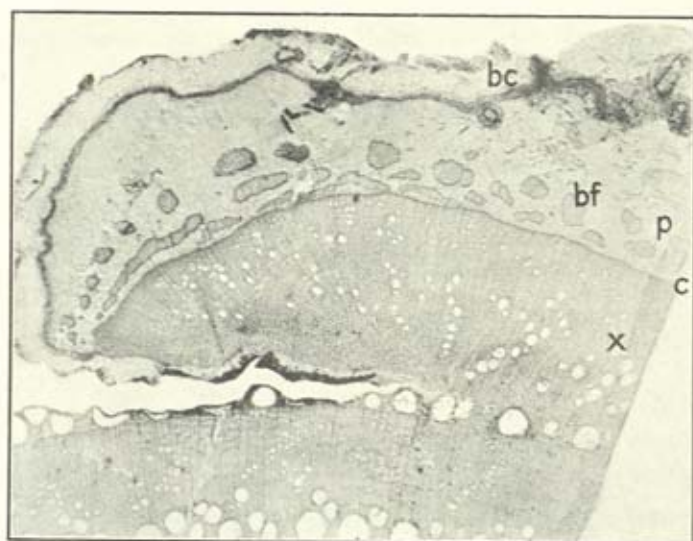


FIG. 2.



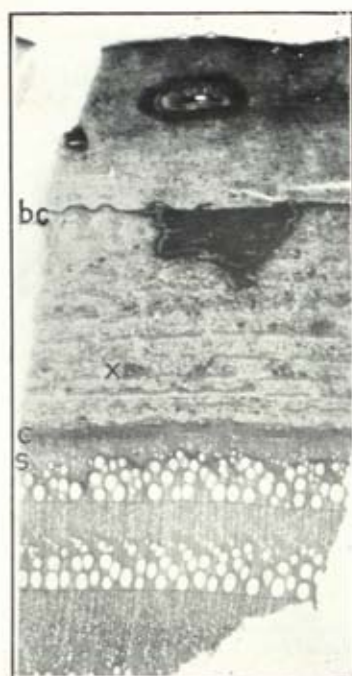


FIG. 4.

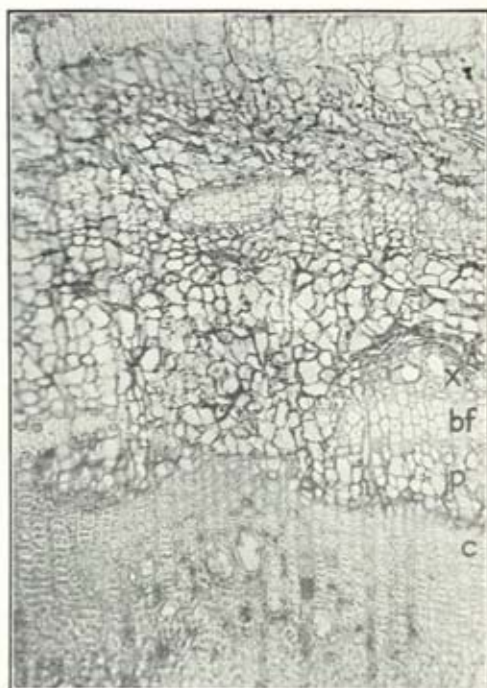


FIG. 5.



FIG. 6.



FIG. 7.



FIG. 8.



FIG. 9.

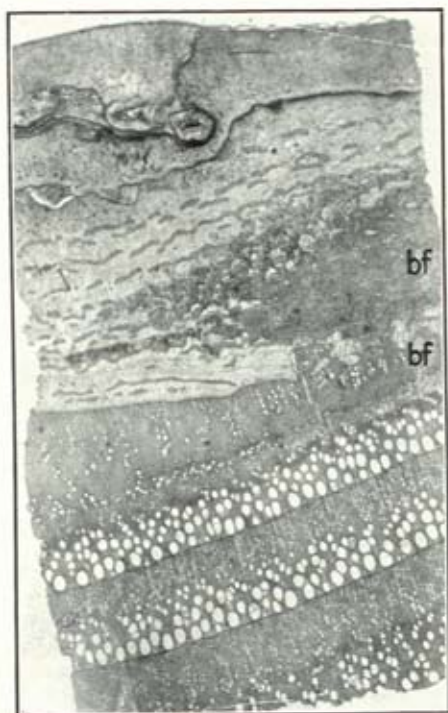


FIG. 10.



FIG. 11.

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3. SCHILBERSZKY, KARL. Künstlich hervorgerufene Bildung sekundärer (extra faszikulärer) Gefässbündel bei Dikotyledonen. *Ber. d. D. bot. Ges.*, 10: 424. 1892.

EXPLANATION OF PLATES.

FIG. 1. Unstained free-hand section. Section cut from a tree eight years old, injected with methylene blue during the latter part of April. The tree was felled in October. Dilution of methylene blue solution was 1 gram to 4 liters of water.

FIG. 2. Auerbach stain. Section cut from a tree nine years old injected in May with meta-cresol 1-1000 G.M. The branch was cut from the tree in October.

FIG. 3. Delafield's hæmatoxylon. Section cut from a ten-year-old tree injected June and July with nitrophenol-para 1-500 G.M. Tree felled in November.

FIG. 4. Auerbach stain. Section cut from sixteen-year-old tree injected with lithium carbonate 1-500 G.M. in July, August, September and October. Tree felled in November.

FIG. 5. An enlargement of a part of Fig. 4.

FIG. 6. Auerbach stain. Section cut from the tree shown in Figs. 4 and 5.

FIG. 7. An enlargement of a part of Fig. 6.

FIG. 8. An enlargement of a part of Fig. 7.

FIG. 9. Heidenheim's iron alum hæmatoxylose. Section cut from a fourteen-year-old tree, which was injected May, June and July with nitrophenol-para 1-1000 G.M. Tree felled in November.

FIG. 10. Auerbach stain. Section cut from a fourteen-year-old tree which was injected in June and July with picric acid 1-1000 G.M. Tree felled in November.

FIG. 11. An enlargement of a part of Fig. 10.

COLOR-PHOTOGRAPHS OF THE PHOSPHORESCENCE OF CERTAIN METALLIC SULPHIDES.

By EDWARD L. NICHOLS.

(Read April 14, 1916.)

Among the most beautiful and interesting of phosphorescent substances are the sulphides prepared and described several years ago by Professors Lenard and Klatt,¹ of Heidelberg. These substances which consist of the sulphide of barium, calcium or strontium, with a small admixture of some metallic salt—usually of copper, bismuth or lead—are prepared by heating with a flux such as sodium sulphate, sodium borate or lithium phosphate. After exposure to daylight or to violet or ultra-violet rays they glow for a considerable time with characteristic colors which depend upon the particular mixture used.

Variations in the brightness of phosphorescence with the time find convenient indication by means of the curve of decay and the effects of temperature, etc., on the intensity are likewise capable of graphic or analytical expression. These relationships have already been extensively studied by the authors just cited and others and in a paper read before the American Philosophical Society in April, 1910, I presented the results of such an investigation. The subtle and fleeting changes of color which occur as the phosphorescence dies away or when the substance is heated or cooled or when we compare sulphides varying in composition, do not lend themselves to such methods of expression. The effects must be seen to be appreciated and it seemed of interest to try to record some of the phenomena by means of color photographs.

Now the glow of even the brightest of these phosphorescent substances is in reality of very low intensity and color-plates such as the Lumière plates used in the experiments to be described are relatively

¹ Lenard and Klatt, *Annalen der Physik*, 15 (1904), also Lenard, *ibid.*, 31, p. 641 (1910).

slow. The total light effect obtained by a single excitation is inadequate for the proper exposure of the plate when used in the camera in the ordinary manner. Indeed it was found in some preliminary trials by Professor G. S. Moler and the writer that a plate placed in immediate contact with a tube containing the phosphorescent sulphide as soon as practicable after intense excitation and allowed to remain for several minutes or until nearly the whole of the total light effect had been utilized, was decidedly under-exposed.

On the other hand the color effects to be recorded change rapidly, especially during the first few hundredths of a second after excitation so that it was necessary to obtain the equivalent of a large number of successive short exposures each made at the particular time after excitation for which the color record was desired.

To this end a special form of phosphoroscope² was constructed by means of which the substance, enclosed in a flat tube of glass about 10 cm. long and from 1 cm. to 1.5 cm. wide, was viewed through a revolving disk with alternate open and closed sectors of 45° aperture. The disk was mounted on the shaft of an alternating current synchronous motor on a 60-cycle circuit and excitation was by a series of five sparks (*E*, Fig. 1) between zinc terminals.

The sparks were produced by the action of the secondary coil of a small step-up transformer with condenser *C*, in the same circuit.

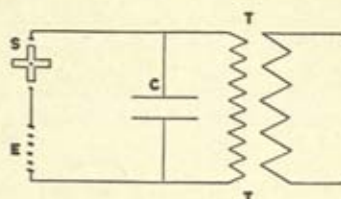


FIG. 1.

A spur wheel of zinc (*S*) was mounted on the shaft of the motor and its four arms passed the two terminals of the sparking circuit with an air space of about 1 mm. The wheel was adjusted so that this passage coincided with successive crests of the alternating-cur-

² See a paper presented by Nichols and Howes at the meeting of the Am. Phys. Society, Washington, April, 1916, abstract *Physical Review* (2), VII., p. 586, 1916.

rent wave and the sectored disk was shifted until the sparking occurred during eclipse, *i. e.*, at the time when a closed sector obscured from view both the sparks and the substance under excitation (see Fig. 2, position 1).

With this arrangement the specimen, which was mounted vertically in a line parallel to the row of spark gaps and distant from them about 2 cm., was intensely illuminated 120 times a second and was visible during intermediate intervals of $1/240$ of a second, each

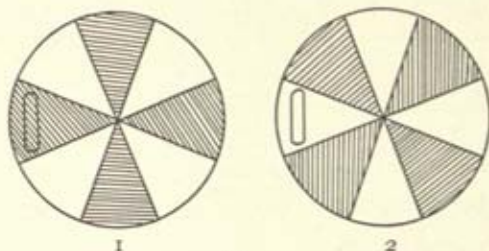


FIG. 2.

beginning about .0001 second after excitation ceased (see Fig. 2, position 2).

For observations during later stages of decay the wheel could be driven slowly by means of a direct-current motor or moved stepwise an eighth of a revolution at a time at the desired rate.

Since some of the most striking changes of color are produced by differences of temperature, the tube containing the phosphorescent sulphide was mounted within a cylindrical Dewar flask with un-silvered walls. The lower end rested in a metal mercury cup while the upper end passed through a heating coil (see Fig. 3). From the bottom of the mercury cup, *M*, a copper rod projected downwards into liquid air. The region at *A* could thus be maintained at a temperature of $+20^{\circ}\text{C.}$, or higher, while the lower end at *B* was at approximately -185°C.

A fairly stable temperature gradient soon established itself and the colors of phosphorescence through the entire range could be observed and photographically recorded.

Excitation under these conditions was obtained by inserting the sparking device within the Dewar flask and many photographs were made in that way; but this is a procedure demanding special pre-

cautions, as the atmosphere above the liquid air is very rich in oxygen and conflagration of the insulating materials and even the metal parts is likely to occur.

The principal phenomena to be studied were those due to:

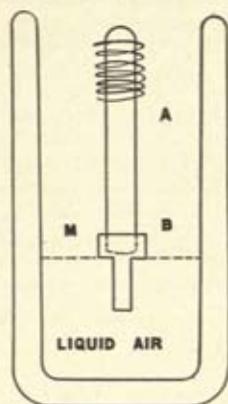


FIG. 3.

1. The change of color during the decadence of phosphorescence.
2. The effect on the color of phosphorescence when excitation occurs at temperatures between $+20^{\circ}$ and -185° .

CHANGES DURING DECAY.

To confirm the well-known phenomenon of change of color during decay it is only necessary to mount one of the sulphides in the phosphoroscope and excite with the disk running at normal speed, *i. e.*, 1,800 rev. a minute. The appearance as viewed through the revolving disk is then that due to its phosphorescence during the interval .0001 to .004 second (approx.) after excitation. If the excitation be stopped by breaking the spark circuit the changes of color as phosphorescence dies away can be followed for several seconds.

In the case, for example, of a sulphide known as No. 33 (Ba , Cu , $\text{Na}_2\text{B}_4\text{O}_7$) the initial tint of red-yellow changes to a deep red. Another preparation, No. 3 (Ca , Bi , Na_2SO_4 ; $\text{CaF}_2\text{Na}_2\text{B}_4\text{O}_7$), which is typical of many, appears bluish green through the rapidly revolving disk and changes very rapidly after the close of excitation to a deep

violet. (Photographs were shown at the meeting illustrating these and similar cases.)

The work of Lenard and others using a very different procedure has shown the spectra of these substances to consist of broad overlapping bands distinguishable from each other chiefly by the mode of excitation, duration, and the influence of temperature and it is clear that in these and similar cases we have to do with two or more such bands.

In the first of these two examples the change of color may obviously be explained by the more rapid decay of the band of shorter wave-length; an hypothesis readily verified by observing the substance as seen through the disk with a spectroscope. What appears as a single very broad band collapses promptly from the green end when the exciting circuit is broken, leaving the red portion only, which persists for many seconds.

We have to do then with a combination of a band of very short duration (having its crest in the green) and a band of long duration in the red and the color at any time after the close of excitation is the sum of the instantaneous values of the two components.

Since the decay of the green band is very rapid indeed, its intensity becoming negligible in a small fraction of a second, the appearance of the phosphorescent surface when observed by ordinary methods is chiefly due to the red component and it appears of a much more ruddy color than when viewed through the rapidly revolving disk. The same is true of all the other barium sulphides studied.

The Ca and Sr sulphides in general appear as greenish blue, pure blue or even violet as in the example cited (No. 3) when viewed in the ordinary manner; but in the phosphoscope they are green, going over into blue or violet after the cessation of the periodic excitation. Here obviously we again have to do with two bands of which the green is of very short duration, while it is not in this case the band of longer wave-length which persists but that of greater refrangibility. It appears in general that these sulphides fall into two distinct classes: Those of which the persistent band is of longer wave-length, *i. e.*, red, chiefly if not exclusively barium

sulphides, and those of which the persistent band is of shorter wavelength.

Thirty-four sulphides examined by the method already described showed color changes in accordance with the foregoing classification.

COLOR CHANGES DUE TO COOLING.

Since the intensity of the band of rapid decay vanishes in a small fraction of a second, ordinary observations of the phosphorescence of these sulphides pertain, as has already been pointed out, to the persistent band alone. It is not possible moreover to isolate the rapid band by the use of the phosphoroscope, since during the brief period immediately following excitation we have both bands present and the color due to their combination.

The slow bands, however, are greatly diminished in intensity by cooling the phosphorescent substance and are often reduced almost or quite to the vanishing point. Thus it is possible by lowering the substance during the experiment to temperatures approaching that of liquid air, to observe the color and intensity of the rapid band, by itself.

When we cool the lower end of a tube of the BaCu sulphide No. 33 with liquid air, as described in a previous paragraph, and observe

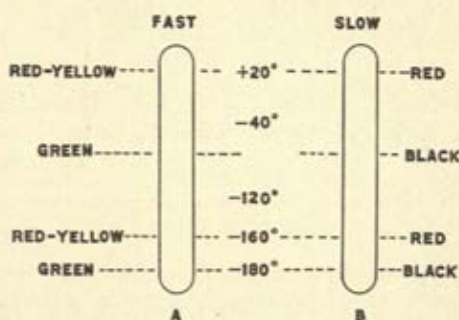


FIG. 4.

its phosphorescence through the sectored disk, the red-yellow of the upper (warm) end merges gradually into a brilliant green occupying the cooler regions below. A red-yellow patch occurs still lower down, while at the very bottom where the temperature approaches

that of liquid air there is a return to green. The distribution of colors and approximate temperatures are indicated in Fig. 4 (A).

That this remarkable distribution of colors is to be interpreted as the result of the killing off of the "slow" red band by cooling and its subsequent recurrence at about -160° , is beautifully confirmed by the appearance of the tube after the entire cessation of excitation. When the spark circuit is broken, the green vanishes at once but the red regions above and below continue to glow for many seconds as indicated in Fig. 4 (B).

In 1910 I measured the change in the phosphorescence of this substance³ effected by temperature. The curve, which is reproduced in Fig. 5, applies to the red band only, since the green band would have vanished long before observations of brightness could be made

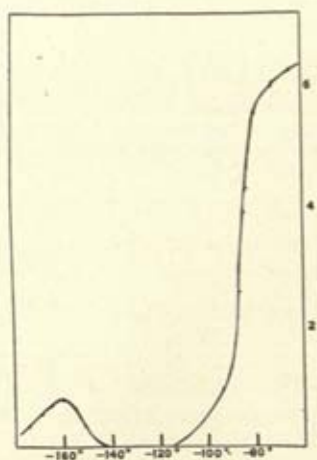


FIG. 5.

by the method then employed. It describes exactly the appearance noted in Fig. 4B, *i. e.*, a rapid diminution on cooling, complete disappearance at about -120° C., a recurrence of measurable intensity below -140° with a maximum at -160° .

All BaCu combinations, so far as examined, have a red-yellow color of phosphorescence at room temperature with the red band of longer duration, but the relative intensity of the red varies greatly

³ *Proc. of Am. Philosophical Soc.*, XLIX., 275, 1910.

with different fluxes and proportions. While the persistence of the green band at low temperatures seems to be a general property of these substances the recrudescence of the red as in the example here considered is not so apparent in other cases. In the other substances of this class it must be regarded either as masked by the brightness of the green component or entirely absent. In the former case one might expect a modification of the green at the temperature in question and in several specimens thus far studied this is clearly the case.

The effect of cooling the phosphorescent sulphides of calcium and strontium is analogous to that just described.

The band of long duration is greatly weakened or disappears;

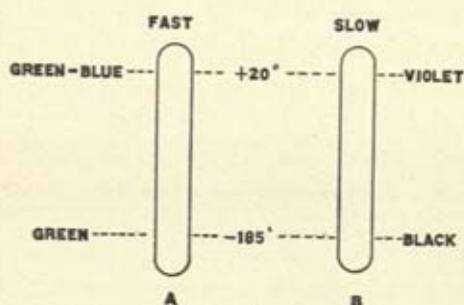


FIG. 6.

the other, which in all these cases, so far as has been observed, is a green band, persists.

Since the band destroyed by cold is, however, blue or violet, the change of color is in the opposite direction from that noted in the case of the barium compounds, *i. e.*, from blue or blue-green to green instead of from red-yellow to green.

The most striking example in this class is perhaps the combination (Ca, Bi, Na_2SO_4 ; CaF_2 , $\text{Na}_2\text{B}_4\text{O}_7$) already referred to. The greenish blue of early phosphorescence, as observed through the sector disk at $+20^\circ$, goes over to a full green of short duration in the cold portions of the tube, the phosphorescence of long duration being in both cases of a remarkably rich pure violet. See Figure 6.

It is obvious that the methods described in this paper bring out from quite a new standpoint the structure of the phosphorescence

spectra of these sulphides and enable us not only to record the changes of color but to explain them.

Many interesting points are still to be determined which are likely to have a bearing upon the theories of luminescence.

It will be possible for example, having shown that the bands of short duration are really separable by cooling from the components of slow decay, to locate these properly by the use of the spectrophotometer and phosphoroscope.

We shall then know whether the green band which persists at low temperatures is the same for all the sulphides or, as is more likely, varies in position and character with the compound employed; in what manner the components of long duration depend on the composition; whether the loss of brilliancy which many of these substances undergo with age, affects both sets of bands, etc.

PHYSICAL LABORATORY OF CORNELL UNIVERSITY,
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COÖPERATION AS A FACTOR IN EVOLUTION.

By WILLIAM PATTEN.

(Read April 15, 1916.)

I.

Evolution is the summation of power through coöperation. For evolution, so far as a science of relative measurements can estimate, is a process of self-maintained growth, or progressive creation; and coöperation, which is the joint action of discrete powers in a common service, is the only knowable way of creating new things and new kinds of power. It is the coöperative action, for example, between atoms, or cells, or organs, or human beings, that creates the new and larger units, called molecules, or individuals, or organisms, or society, all of which are endowed with powers different in quantity and in quality from those of their constituent parts. These larger units, with their appropriate powers, then constitute the ways and means for further coöperative action and for the creation thereby of still larger units with new creative powers.

The duration and progress of evolution depends on the attainment of a fundamental righteousness in the methods of coöperation, the "right" methods being attained by "accident," by "trial and error," and by "design." The process, in any case, is inevitably accumulative, or a process of growth, because of the inherent creative and saving power of coöperation.

Any change in the existing methods of coöperation either checks, or accelerates, the rate of evolution, or modifies its direction, the result depending on the creative value of the change.

Given equal time and opportunities, the degree of progress, or the length of the genetic line, indicates the creative value of the methods of coöperation that were used to attain the result. The methods of internal organic coöperation of the animal, for example, have yielded incomparably higher products than those of the plant,

although one has had the same length of time for development, and the same opportunities in the world at large, as the other. On the other hand, the prevailing methods of coöperative action between the plant kingdom and the animal kingdom are essential factors in the evolution of life as a whole, and in the creation of the highest products of both kingdoms. Hence our estimates of values will vary with our visual angle; that is, according as we consider each method or individual by itself, and as an end in itself, or as several different methods, or individuals, acting together for a larger end.

As the vertebrate has progressed farther in the same time and in the same general surroundings than the plant, or than the starfish, or the snail, it is well to inquire what are the basic methods of structure and organization on which this progress depends.

In such an inquiry, we may confine our attention to the internal structure of the individual organism, ignoring, for the time being, its external environment; for, in the main, the external environment is a common factor, affecting all kinds of life in the same way; any special response of the individual to its environment is due to the special structure and special internal life of that individual.

The external environments, for example, of the dog and his master, of father and son, of the bee and the flower, may be essentially the same, but these environments will not affect all their residents in the same way. The things in them that coöperate with the life of one may have no existence in the life of the other because the inner structure and response of the one to the other is different.

Thus while the initial source of our knowledge of living things is external, as our knowledge of these things deepens, it tends to express itself more and more in terms of their inner mechanism of response and in the coöperative action of their various internal parts.

The older school of naturalists laid too much emphasis on the external environment of the completed individual, and of necessity ignored its complex inner mechanism of response to the outer world, because that mechanism was inaccessible to them. The more modern school of genetics lays too much stress on the beginning of individual life, on the assumption, expressed or implied, that at the beginning of things, the solution of vital problems is simpler and

easier, and that their solution carries the solution of end results with them.

This is only a fraction of the truth. The beginning of life is apparently simpler than the end because fewer questions are asked. The later structures have not at that time arisen and do not then call for explanation. But no formula for Alpha will serve for Omega. Every phase and stage of life brings its own problems; each one has its own creative power. The biologist must consider each of these problems as they arise, individually and organically; both as independent units and as dependent members of a genetic series, or organic whole. For each phase of life is created by that which precedes, and is the creator of that which follows. For this reason, while every science is tributary to every other science, each one is the rightful arbiter in its own field. The sociologist, who now leans too heavily on the biologist, is as likely to be led astray as those who formerly learned too heavily on the theologian. The true sociologist, like the morphologist, is master in his own field, and in things sociological it is his business to teach the biologist and the theologian. For he alone is best able to estimate the creative value of the coöperative innovations upon which each stage of social progress stands, just as the morphologist can best estimate the creative value and directive influence of perforate gill clefts, and the four-chambered heart, or a particular mode of dentition, without reference to germ-plasma and chromosomes, and without waiting for the students of heredity to decide for him whether acquired characters are inherited, or not. The morphologist knows that the tongue, the hand, the brain, the skeleton, and the yolk of the egg have a directive and creative value that is wholly their own product, a value which can never be measured in terms of chromosomes, or in terms of any other remote antecedent conditions, any more than the properties of water, or protoplasm, or consciousness, can be measured, or be profitably discussed, in terms of chemical elements. Each part and organ, at each stage of its progress, must be measured in terms of its own existing properties, not in those of its constituents, nor in those of remote antecedent conditions.

II.

That coöperation is an important agent in human and in animal societies has often been recognized, but, so far as the author is aware, it has always been considered as something unusual or exceptional in nature, and has been chiefly or solely attributed to the instinctive or intelligent actions of social organisms.

We maintain, however, that coöperation is a universal creative and preservative agent. Its sphere of activity includes cosmic, as well as organic, social and mental processes; its directive influence is as commanding in the one field as in the other, and its creative and preservative power is no less effective whether it is called into action by "trial and error," or by "accident," or by "design."

The broader interpretation herein proposed provides a rational basis for the identification of the two great protagonists in nature: construction and destruction; it helps us to visualize the evolution of world power through the conversion of disorder into order; and it provides a common starting point, a common agency, and a common terminology for all students whose subject matter is the product of evolution, or growth.

The familiar terms "evolution," the "struggle for existence" and the "survival of the fittest" are essentially meaningless and unsatisfying terms because they fail to indicate what is good and what is evil, or to give any comprehensive explanation of how things come into being, why they endure, and how they increase in power. These questions lie at the root of all organic or inorganic products; they are the fundamental questions which all sciences and all religions seek to answer.

But when we realize that evolution is the summation of power through coöperation, that what we call "evil" is that which prevents or destroys coöperation, and "good" is that which perpetuates or improves coöperation; when we realize that the "struggle for existence" is a struggle to find better ways and means of coöperation, and the "fittest" is the one that coöperates best—we shall then realize that science and religion and government stand on common ground and have a common purpose. Until this basic truth is recognized there can be no common goal for intellectual endeavor; no common

rules for individual and social conduct; no common standard of what is right and what is wrong; and no common knowledge of that which creates and preserves and that which destroys.

That all evolution, or growth, is the summation of power through coöperative action is axiomatic. But while this axiom does not define what power is, nor what the nature of the ultimate act of coöperation is, it goes far toward satisfying our intellectual demand for some universal instrument of creation and preservation, and at the same time it provides us with a single standard for the measure of service. For service is always the product of coöperative action; it is that which creates and preserves new products by new ways and means of coöperation.

But the extent to which coöperation is attained depends on the extent to which "righteousness" is attained; for coöperation cannot take place except the right things are brought into a definite time and space relation to one another. The chief service of coöperative action, therefore, consists in the conveyance of the right kinds of power to the right times and places for further coöperative action.

The universal measure of progress, therefore, is the progress of coöperative action by the part and the whole for the part and the whole.

In the world at large, progress is measured: (1) by the diversity of its products; (2) by the power of these products to sustain one another through mutually profitable exchange; and (3) by their power to create, with the profits, a better system of coöperative service.

In the organic world, the individual plant, or animal, is created and preserved: (1) by its internal system of organic coöperation; (2) by its coöperative response to the larger cosmic processes in which it resides; and (3) by its coöperation, directly or indirectly, with other living organisms.

And the welfare and security of the entire fabric of organic life, and of its highest products, is assured by conserving the welfare and security of all its coöperating parts.

III.

But every analysis of nature leads to the question of growth, for growth is everywhere an underlying phenomenon in evolution. While the basic impetus to growth is doubtless unknowable, the conditions which divert, restrict, or liberate that impetus may be observed and estimated.

Our interpretation of nature is based largely on the following conclusions concerning growth, which are herewith submitted, without, for the present, further discussion or defense.

1. Morphology is the science of form, and form is the outward expression of growth.

2. The *vis a tergo* in life is the product of internal coöperative exchange (metabolism).

3. Growth is profitable exchange with the outside world, or the local accumulation of those agents whose demands are the impetus to exchange.

4. The rate at which growth proceeds depends: (*a*) on the inherent nature of the growing point, or its affinity or "demand" for more materials; (*b*) on the distribution of supplies; (*c*) on the capacity of the conveyers, that is, on their capacity to convey commodities to and from the growing points, or the growing points to the sources of supply; and (*d*) on the coöperative, or creative, value of the service rendered by the exchange.

5. A local population of molecules, cells, or human beings, cannot give or take more than the existing conveyers can carry; nor can exchange take place beyond the point where delivery and removal can be made.

6. The capacity of a conveyer depends on the load it can carry, the distance it can be carried, and the speed. The factors, load, distance, and speed, vary with the commodity; and different methods of conveyance are required for different commodities. In human society, there is one method for the individual man, one for water, coal, groceries, and ideas. In protoplasm, different methods are required to convey solid and liquid foods, oxygen, and waste products, or to transmit light and other stimuli.

7. In all such cases, the capacity of the conveyers is limited. It

is temporarily limited by the methods of constructing, or arranging, the conveyers; these methods may be changed or improved. It is permanently limited by the inherent nature of the conveyer, and by the nature of the things to be conveyed; these conditions cannot be modified or improved.

8. But there are no limits to the demands for more materials, for the old demands remain till satisfied, and being satisfied, create new demands.

9. When many commodities are required at a given point at the same time, the rate of growth is determined by the maximum capacity of the slowest conveyer.

10. Since there are unlike local rates and directions of conveyance, unlike local growths arise, unlike in volume, or in quality, or in both. These products of growth become the new agents by whose coöperative action further growth is made possible.

Evolution, therefore, is not due to the subdivision of labor between like units; rather is it that growth inevitably creates different kinds of laborers thereby making the subdivision of labor the imperative condition of their existence.

Growth, therefore, creates the power which is used to satisfy its own demands, and a surplus power, or profit, for freedom of action, which is then used to experiment and explore, thereby finding better ways and means of satisfying its demands.

The same principle may be expressed in commercial or economic terms instead of dynamic terms: progress cannot take place unless the creative value of the service performed pays the cost of the service and yields a surplus profit for freedom. Freedom then becomes the instrument for the discovery, or invention, of better ways and means of service.

11. Growth inevitably creates diversified conditions which tend to check its own progress till released by better coöperation. For growth reduces the immediately available supplies, thereby requiring greater expenditures to procure them; moreover the new internal conditions created by growth create new products, with new demands, faster than the right ways of administering them can be found.

In order, with diminishing supplies, to meet the increasing de-

mands of a growing body, the conveyers must ultimately be utilized to their full capacity; when that point is approached, the rate of growth will diminish, for the expenditures for conveyance will tend to exceed the creative value of the products. The previous rate of growth can then only be maintained by economizing, or improving, or by extending, the ways and means of conveyance. That is to say, either the lines of conveyance must be lengthened, or the rate of conveyance accelerated, or the powers of penetration increased.

But better conveyance simply means better methods of coöperation to that end between the older products of growth; that is, it means the using of those methods which yield more profitable exchange, or which create still more voluminous and diversified products. These new products then constitute the new means to a still larger end; for the creation of diversified products is essential to the invention of new methods of organic coöperation.

12. Growth, therefore, is automatically controlled. For since the rate and the extent of growth depends on the capacity of its conveyers, growth will be checked whenever the new demands created by growth approach the full capacity of its conveyers, and it will be released when better ways and means of conveyance have been found. Thus growth always tends to outrun coöperation, and better coöperation always produces more growth, with new imperfections which still better coöperation alone can remedy.

13. The rate and direction of evolution varies greatly from time to time, according to the methods of coöperation utilized.

These changes of pace and direction in evolution are the real basis of our systems of classifying the organic and inorganic products of nature.

14. The principal kinds of conveyance in the internal organic life of the individual are nervous, alimentary, vascular, and excretory; in the external life they are cosmic circulation, locomotion, and communication. All the epoch-making events in organic evolution are due to the introduction of better service in one or more of these methods of conveyance.

15. The changes of pace in organic evolution, following the adoption of important improvements in coöperation, in retrospect appear as gaps of larger or smaller magnitude, between classes, orders, and

species. These apparent gaps would still be present, even though the records were complete.

16. Growth follows the easiest and most profitable lines of conveyance, and its products accumulate along the lines of least resistance. Thus the form and structure, or morphology, of a given organism is the physical machinery of life and the outward expression of its internal methods of coöperative action. Life (physiology) is the act of creating that machinery.

The rapid rate, the certainty, and the precision of embryonic growth reveal the efficiency of the initial, established methods of organic coöperation. The universal onset of individual senility and death—the one the accumulation, the other the culmination of uncoördinated growth—reveals the present imperfections in the methods of organic coöperation. But the perpetual renewal and reinforcement of individual life, to which evolution testifies, reveal the larger process, and are an assurance of the immortality and perpetual progress of organized nature.

17. Coöperation in the inner life of the individual is a prerequisite to coöperation in the outer life. It is the means by which it attains greater power and that larger physical volume that inevitably goes with larger power; and this larger organic power of the individual is the instrument by which it finds the larger sources of supplies, and the better ways of cosmic and social coöperation; it is the instrument by which it attains that which is good for itself, and avoids that which is evil.

And the demands of its larger volume is an added obligation for better internal and external coöperation in self-preservation.

18. The same laws which prevail in the inner and outer life of animals and plants prevail in the social life of man. Man's social progress is measured by the degree to which he has extended the mutually profitable give and take of coöperative action beyond himself, into the family, tribe, and state, and into the world of life at large. The chief agents of civilization—language, commerce, science, literature, art, and religion—are the larger and more enduring instruments of conveyance which better enable the part and the whole to avoid that which is evil and to find that which is good, and which yield a larger surplus for freedom.

IV.

Let us consider a few special cases that may serve to make our meaning clearer. We shall have space to refer to a few of the more important points only.

Let us assume that equal units or cells are growing under uniform conditions, suspended in a medium from which they draw their varied supplies. Such units will tend to form a solid sphere, increasing in volume till its radius is nearly equal in length to the longest line of conveyance requisite for metabolism (Fig. 1, *A*). The sphere might enlarge beyond that point, but if it did, an ever larger central space would be formed, filled with fluid, or non-living materials and the thickness of its living walls could not be greater than the longest line of effective conveyance through protoplasm, nor less than the one necessary for structural stability, or cohesion.

Growth in a spherical form beyond either of these limits, would be impossible. But since there are more such lines of exchange, in a cylinder or disc, with two or three unlike axes, than in a sphere of equal volume, as fast as all of the possible lines of conveyance are occupied, the spherical body, of necessity, assumes a more and more discoidal or cylindrical form, *C*, *E*. This change of form cannot be regarded as an extraneous "variation" to accommodate growth; it is the inevitable result of growth attaining its fullest expression. It marks the successive steps in the attainment of the maximum length of the lines of conveyance, the attainment of the maximum number of such lines, and the accumulation of the products of growth along the lines of least resistance.

When the cylindrical, or discoidal, body has reached its limits of growth, still further increase would be possible by opening up the interior, *D*. But here again the increased dimensions attainable by this improvement in conveyance are limited, for the walls could not exceed a definite thickness without the formation of a new barren area (cœlomic cavity) between the inner and outer surface of the walls, and when that limit was reached, growth should again cease.

But the inevitable effects of these changes, even if we assume that no minor complications arose, would be very great. They would tend: (1) to orient the cylindrical, or disc-shaped body to the chief

external lines of force acting upon it; (2) to determine its own direction of movement, and thereby determine its distribution in space; (3) to establish definite internal lines of conveyance, unlike

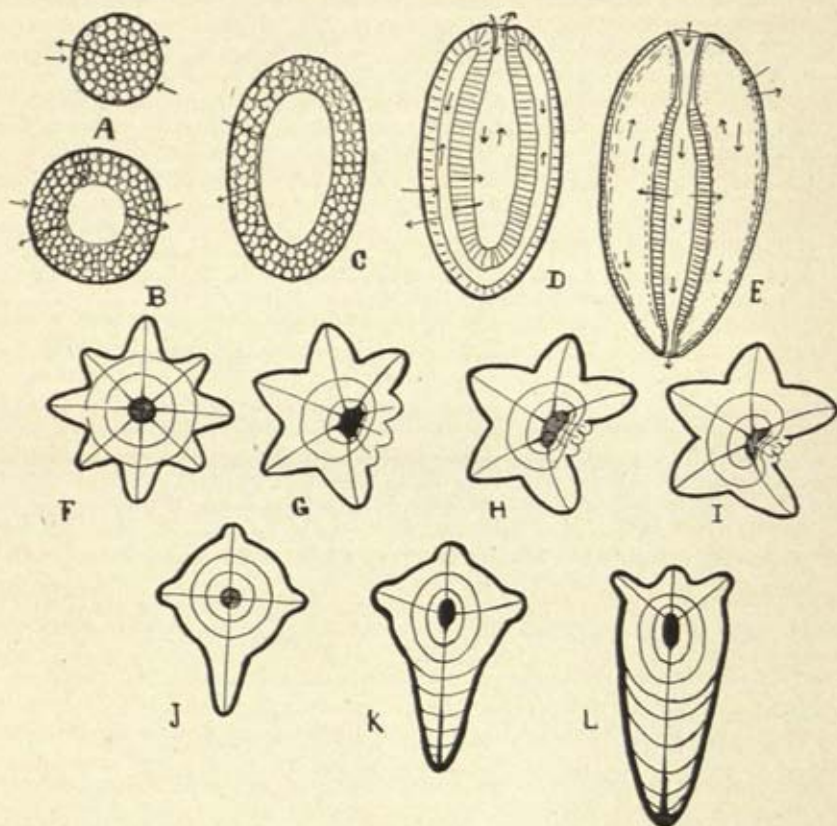


FIG. 1. A-E. Diagrams indicating the lines of exchange in a hypothetical growing body suspended in a nutrient fluid, and the form and structure it would assume if growth followed the lines of easiest conveyance and its products accumulated along the lines of least resistance.

F-I. Diagrams to illustrate how local inequalities in radial growth would be obliterated and the original asymmetry restored by the tendency of the other parts to grow along the paths of least resistance.

J-L. Diagrams to illustrate the conversion of radial growth into the apico-bilateral growth, the body of the radiate type, J, becoming the head of the bilateral type, L. The new cylindrical body supplants the old spherical one owing to the greater economic advantages and creative power of linear and bilateral distribution over radial distribution.

in direction, in content, and in speed; solid bodies passing freely in and out of the interior, and various other agents passing through the walls from within outwards, and still different agents in the opposite directions from without inwards; and (4) the character of the structures produced along the lines and points of unlike conditions would necessarily be unlike in texture and arrangement.

This purely hypothetical case is cited to show that a progressively diversified structure, reacting to the outside world at each successive stage in its own peculiar way, is an inevitable accompaniment of growth, whatever the initial nature of the growing material may be. That is, the form and the structure of such an organism are the resultant products of an internal growth, which follows the lines of easiest conveyance, and whose products accumulate along the lines of least resistance. And the structure of the organism so produced determines its reaction, as a whole, to the outside world. On the coöperative value of that reaction depends its survival, or elimination, or the particular time or place, or sphere, of external environment within which it may endure.

The obvious conclusion is that it is futile, and essentially unscientific in method, to seek for the "explanation" of the structure and function of an adult organism, in terms of germinal units, when the only "explanation" to be found, if any, is in the analysis of a long series of internal and external conditions, and when the things to be explained are the last terms of the series, not the first.

A body produced in the manner indicated above would have the essential characters of a radiate animal, or one growing at equal rates along its corresponding oral radii. Two principal modifications of this method of growth might arise, due to some constant local condition: namely increased tangential growth, or increased growth along one radius. The former, if carried to an extreme, would tend to form a spiral, or might revert to the original radial form (Fig. 1, *F-I*). Such a method of growth carries with it obvious mechanical difficulties and no apparent advantages. The uniradial method, if carried to an extreme, leads toward the bilateral type of apical growth, and carries with it those great mechanical and economic advantages which have led to its retention and elaboration in all the more highly organized animals (Fig. 1, *J-L*).

But none of the higher animals begins its life as an isolated point within a nutrient solution. It is true that an adult animal may be sessile or free, and the mode of life adopted has an important moulding influence on its form and action. But what is more important, because more constant and universal, is the fact that practically every individual metazoan, from the very outset, begins its life as a sessile organism, for it is attached to a more or less inert spherical body (the egg yolk), whose store of non-living contents tends to increase in volume with the progress of evolution. The growth of the embryo is initiated at some point in that body, usually near its surface. Under these conditions, the products of growth inevitably tend to take on the form of a four-layered film, growing in an apico-bilateral direction, with a distributing space, or *cœlom*, between the layers, because that way provides the most economic solution of the initial problems of exchange upon which growth depends, and the most accessible places for the accumulation of the products of growth; moreover it is the only way in which the more voluminous specialized growth of the higher organisms can take place.

The volume of the egg, or its circumference, at once determines the distance the film has to grow in order to enclose the yolk, and the volume determines the amount of growth that may occur before taking in new food supplies from without. But the volume of the egg food cannot change the graded sequence of time and space conditions that must inevitably appear in a film growing over the surface of a nutritive sphere.

These graded series of time and space relations determine the basic lines of conveyance and growth, which in turn are expressed in terms of structural gradients, or axes and surfaces, such as the gradient to the right and gradient to the left, gradient from head end to tail end, from the neural surface to the hæmal surface, and from the outer layers to the inner layers.

The fact that in all apico-bilateral growth the lines of unlike time and space conditions created by the progress of growth coincide with unlike morphological structures is presumptive evidence that these conditions are essential factors in the creation of those structures and that they are the underlying cause of the homologies in

serial organs and concentric layers which prevail throughout the entire series of segmented animals.

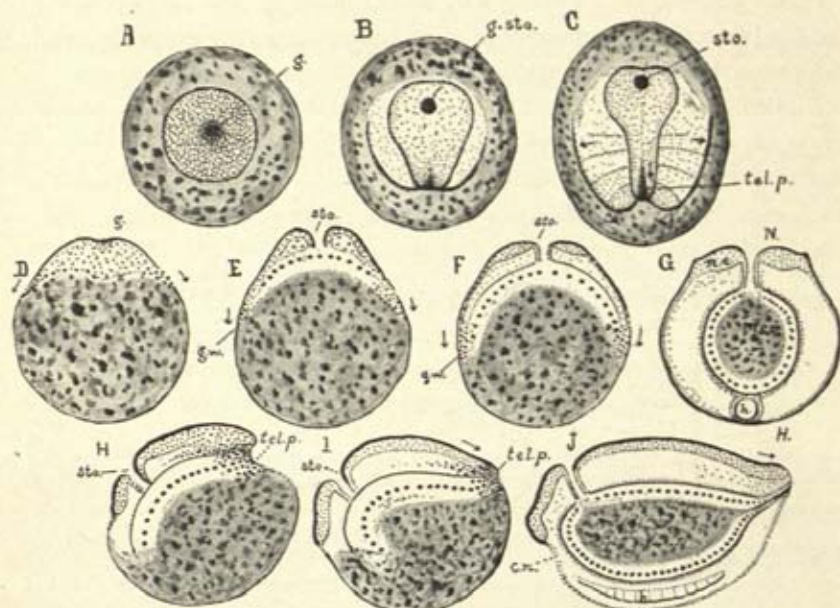


FIG. 2. Diagram to illustrate the transition from the radial to the apico-lateral type of growth, in an arachnid embryo growing on a spherical yolk surface.

A-C. Surface view showing relation of the gastrula stage (radial type) to the apico-bilateral type; also the relation of marginal growth (conrescence), apical growth, blastopore, primitive mouth, and telopore, to one another.

D-G. Same, in transverse section.

H-J. Longitudinal sections showing the four primary channels of exchange, nervous system, alimentary canal, heart, and coelom.

With the growth of the film around the egg, the great landmarks in the morphology of segmented animals may be definitely located: namely, head and tail end, right and left sides, and neural and hæmal surfaces; and the three great channels of conveyance: nerve cord, alimentary canal, and heart, with the segmented channels arising from them, are definitely established (Fig. 2). It might well be said that these landmarks are as unmistakable as the north and the south pole, or the right and left hand, if it were not for the fact

that they are persistently confused in practically all of our text books, a condition chiefly due to the incubus of an ancient terminology that had its origin before the days of embryology; a terminology based on the position of the animal in locomotion, not on its internal structure and its mode of growth.

The peculiar advantages of bilateral apical growth over the radial plan, are apparent when we examine the embryo of one of the higher invertebrates, such as a scorpion, or *Limulus*, where all the important organs are clearly laid down in triaxial gradients coincident with the chief lines of conveyance (Fig. 3).

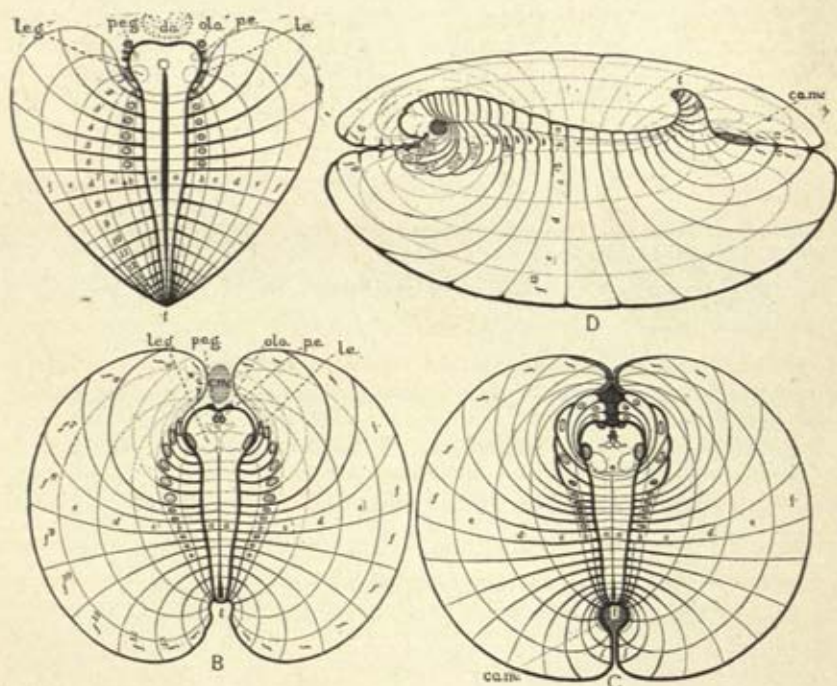


FIG. 3. Diagrams (mercator projections) of arachnid embryos showing how apico-bilateral growth on a spherical surface follows the lines of easiest conveyance and least resistance, thereby determining the chief morphological features of the embryo. From Patten, "The Evolution of the Vertebrates and their Kin."

In the radial plan, there are only two unlike sides, oral and aboral, while innumerable homologous points on corresponding radii,

in their time and space relations to the whole, are alike. In the apico-bilateral plan, there are six unlike sides, and no two points in the whole body are exactly alike.

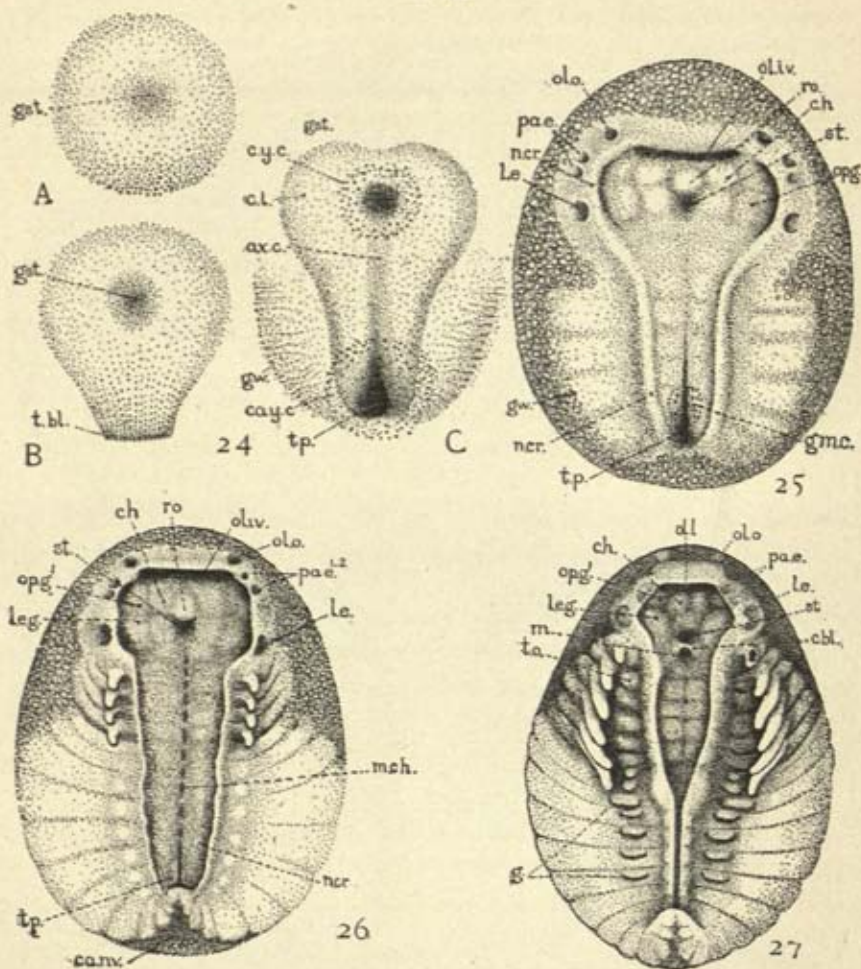
It is this greater diversity in local conditions, capable of infinite expansion, that ultimately creates in the higher, segmented animals the greater diversity in organic products so essential to coöperation and the subdivision of labor.

At the same time it will be observed that the location of the various organs fixes the location of the points of intake and discharge of special commodities thereby establishing a certain necessary order, or sequence of events, in the passage of these commodities through the three great channels of conveyance.

But a linear arrangement of many similar organs, so characteristic of primitive metamerism, would not, in the more voluminous stages of the higher animals, give fullest expression to the latent possibilities of apical, bilateral growth. That is brought about by the gradual breakdown of metamerism, most clearly marked at the cephalic end, and chiefly due to the reduction in the number of multiple parts and to the concentration of functions according to a definite linear order at those points best fitted for the performance of their function. That is to say, in the rearrangement of organs that inevitably follows increase in volume, or in the "competition" of organs for position, each function, as in a growing, well-organized factory, tends to become established in that place in the system where it thrives best, or coöperates best, and for that reason is best able to perform its function. And this tendency will be perpetually operative because of the greater coöperative and creative value of its service to the whole organism when it is so placed. But any arrangement of functions must be subject to the previously established fundamental order of inflow and outflow through the three great channels of exchange: nervous, alimentary, and vascular; to the mechanical requirements of organic and bodily movements; to the inherent limitations in the tensile strength of protoplasm; and to its powers of resonant response.

The history of the evolution of the arthropod-vertebrate stock, covering a period of many millions of years, is chiefly the history of the growth of old organs, the addition of new ones, and the per-

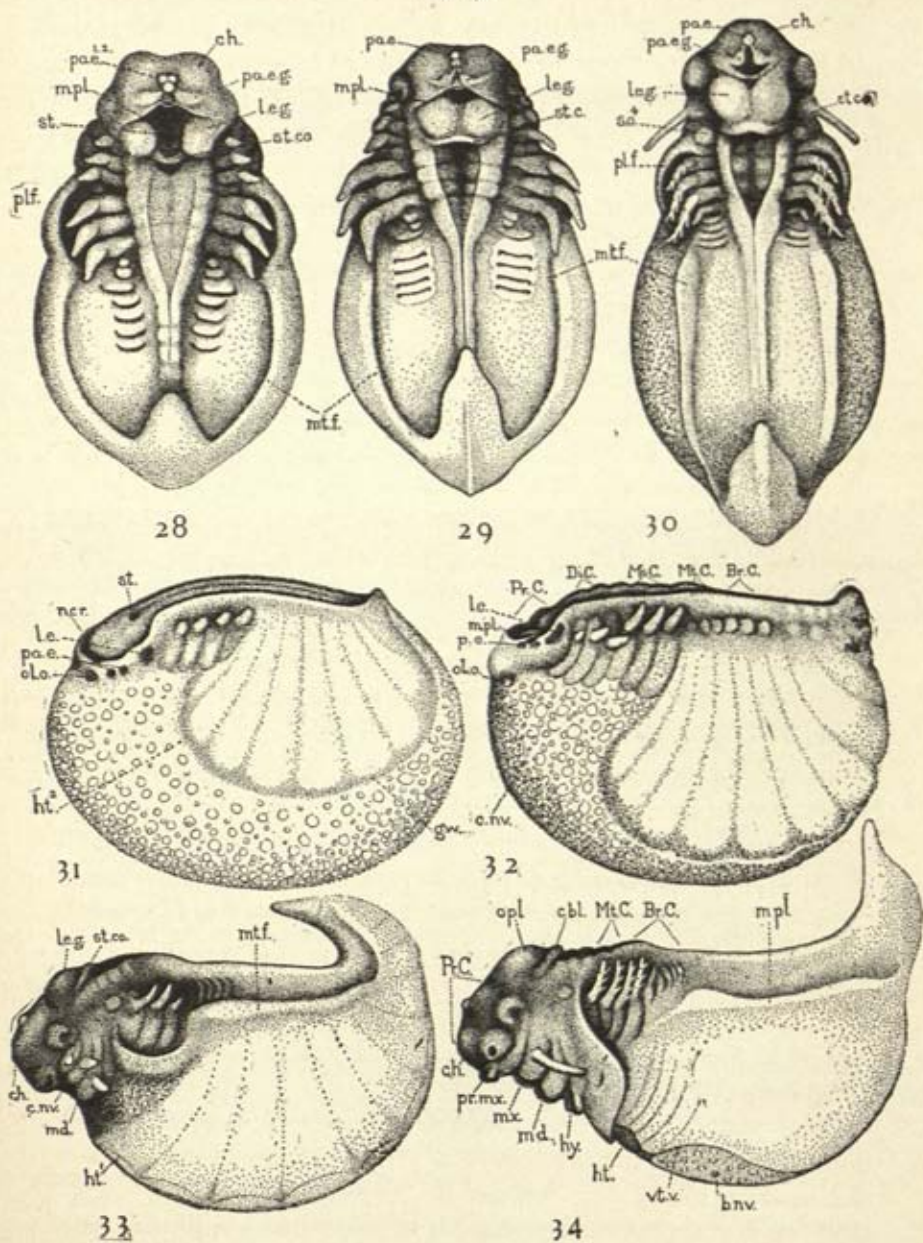
FIG. 4a



FIGS. 4a and 4b. Diagrams illustrating the embryonic development of an arachnid embryo and the hypothetical transition stages to one of the vertebrate type. For further explanation, see Patten, "The Evolution of the Vertebrates and their Kin."

petual readjustment of the new and the old to one another in such a way as to give better organic coöperation. And because of this improvement in organic coöperation, the individual organism inevitably increases in volume, in power, and in freedom.

FIG. 4b.



If we compare the embryo of an arachnid, scorpion, or *Limulus*, with that of a primitive vertebrate, the basic similarity in their mode of growth, the arrangement of their parts, and the natural transition of one type into the other, is clearly apparent (Figs. 4a and 4b).

In both cases, there are in their appropriate places, the medullary plate, the chief sense organs, the neuromeres, somites, lateral plates, heart, primitive streak, notochord, and germ cells; there is also the inevitable concrescence of the germ-wall as it spreads in an apico-bilateral direction over the spherical surface of the egg, as well as many other more detailed resemblances that we can not go into here.

All these structural resemblances show that the chief points of intake and discharge, the basic routes for the conveyance of commodities, and the sequence of way stations and terminals, that are so characteristic of the vertebrate stock, are already well established in the higher members of the arachnid stock.

But there are some striking differences which we will briefly consider, as they also illustrate the principles we have in mind. The three most important ones are as follows:

1. In the arachnids, the stomodæum, or œsophagus, passes through the floor of the medullary plate, while in vertebrates it lies in front of it.

2. In arthropods, there are several pairs of jaw-like appendages which are located on the neural surface, and which, in chewing or biting, move alternately in a right and left direction. In typical vertebrates, the jaws consist of one or two unpaired arches, the posterior arch being freely movable in an antero-posterior direction.

3. The gill chambers of the vertebrates open into the alimentary canal, while, in arachnids, they do not.

In at least two of these cases, the differences are more apparent than real, for the prevailing methods of growth in the arachnids, if carried further, would ultimately lead to the conditions found in the vertebrates.

That is to say, the concentration of the cephalic neuromeres in the head region of the arachnids has already narrowed the stomodæal opening through the floor of the forebrain to a minute canal barely large enough for the passage of fluids, thereby compelling the great majority of arachnids to adopt a liquid diet.

Moreover the arachnid medullary plate, by a process of embryonic invagination and overgrowth, barely falls short of forming a closed chamber. Neither of these processes could be carried much further without either completely constricting the œsophagus, or shutting up the mouth inside a hollow brain. Such an event would be fatal

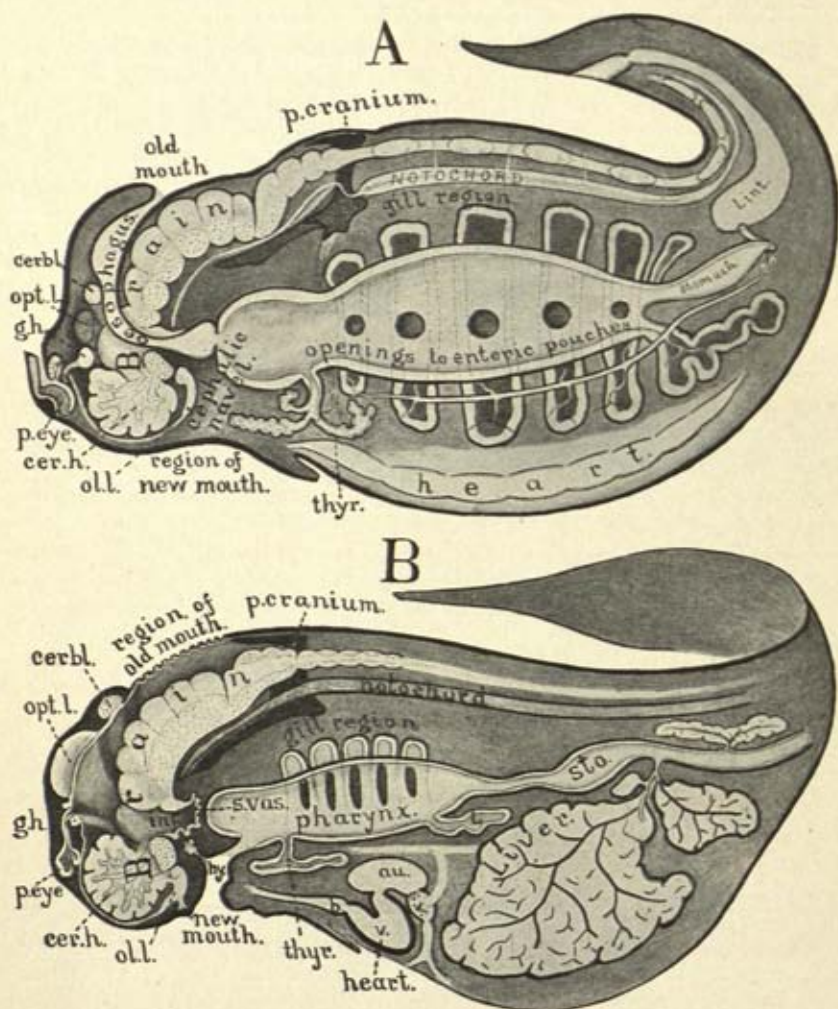


FIG. 5. Diagrammatic sagittal sections of the arachnid and vertebrate type of embryos. For further explanation, see Patten, "The Evolution of the Vertebrates and their Kin."

unless a new opening into the alimentary canal were already available elsewhere. Such an opening is available in what I have called the cephalic navel, a temporary embryonic opening into the enteron, lying on the hæmal surface of the embryo in a region corresponding to that where the vertebrate mouth is located.

What has probably taken place, then, is this: in the vertebrates the old invertebrate œsophagus (Fig. 5, *A*) has been gradually choked up by a vigorously growing nervous system and its external opening completely enclosed within the brain chamber. A new entrance to the alimentary canal was then established through an old channel, of unknown significance, in a more convenient place. The remnants of this old, shut-in mouth and œsophagus are still conspicuous features (otherwise inexplicable) in the brain of all vertebrates, *i. e.*, the infundibulum, the saccus vasculosus, and the large opening in the roof of the fourth ventricle, now closed by a thin membrane, the choroid plexus (Fig. 5, *B*).

The position of the jaws is also changed by the same cause, for the great size of the embryonic forebrain, at an early period, lifts the head of the embryo off the surface of the egg, and forces the jaws, or oral arches, apart, toward the hæmal surface, where they converge around the new oral opening (Fig. 4, 31-34). At least three pairs of arches are involved in this movement, and the important steps in the process may still be observed in many vertebrates.

The transfer of all three pairs of oral arches to the hæmal surface may be readily observed, although heretofore overlooked, in frog embryos (Fig. 6). Their ultimate union, along an elongated median depression, gives rise to the fronto-nasal process, the maxillary and mandibular arches, and gives us the key to the morphology of the facial region in all the higher vertebrates.

Similar conditions may be seen in the adult stages of a very primitive living vertebrate, *Myxine* (Fig. 7, *E*), and also in the Ostracoderms, which form the connecting link between the giant sea scorpions and the true fishes. In *Bothriolepis* (Fig. 7, *A'*) both the maxillary and mandibular arches are provided with bony plates located on the hæmal side of the body and which work against each other in a transverse direction, thus furnishing an instructive tran-

sitional stage between the typical arthropod and typical vertebrate jaws.

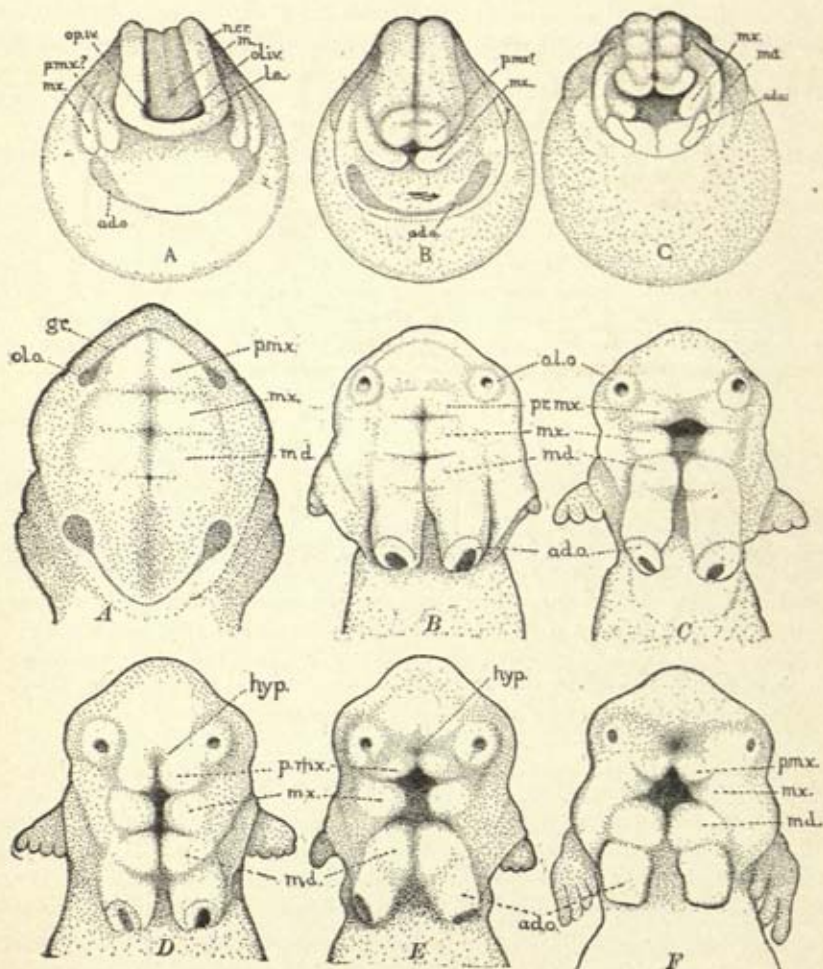


FIG. 6. Development of the jaws of the frog. The figures show the presence of three pairs of appendage-like oral lobes of the arthropod type, their migration from the neural to the hæmal side of the head, and their union to form the transverse unpaired upper and lower jaws of the vertebrate type. From Patten, "The Evolution of the Vertebrates and their Kin."

Evidence of a similar condition is seen in man, for one of the chief events in the embryonic growth of his face is the concrescence

of several pairs of oral arches to form the unpaired jaws, and some of the adjacent organs of the adult (Fig. 8).

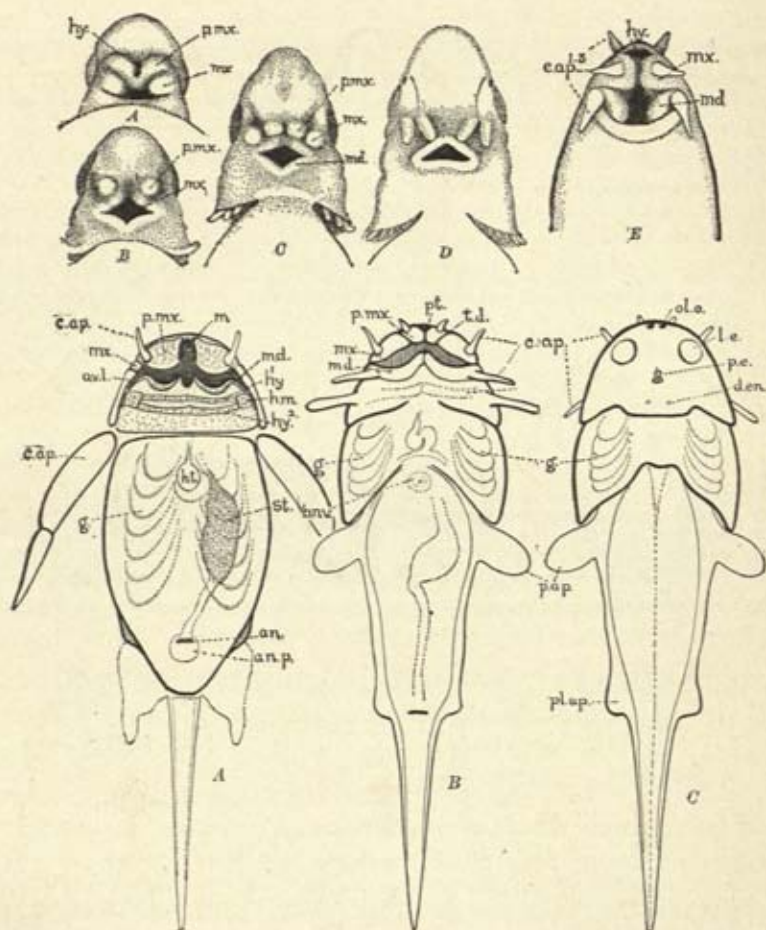


FIG. 7. A-D. Development of the jaws of the sturgeon. After Salsky. E, head of *Bdellostoma*, a primitive vertebrate, showing three pairs of oral appendages similar to those in the frog embryo. F, *Bothriolepis*, an ancient, extinct animal of vertebrate affinities, with mouth parts intermediate in character between those of arthropods and vertebrates. From Patten, "The Evolution of the Vertebrates and their Kin."

The conditions that led to the opening of the ingrowing gill chambers into the outgrowing enteric diverticula are not apparent.

although such an opening seems to have taken place at several different times in the evolution of the arachnid stock.

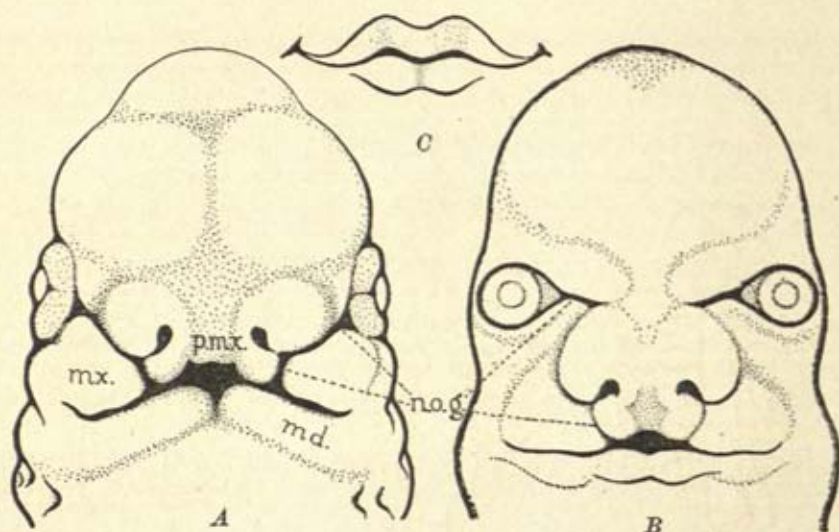


FIG. 8. Human embryos showing the three pairs of oral arches that help to form the face and jaws. From Patten, "A Problem in Evolution."

But the facts we wish to emphasize here are that the communication in vertebrates of the gill chambers with the alimentary canal has two very different effects: (1) it greatly increases the respiratory power by directing the respiratory current through the gills in a constant direction, that is, in at one side and out the other, instead of in and out through the same opening; and (2) it at once makes it impracticable to carry on digestive action at any point in front of an open visceral cleft.

The thyroid gland is doubtless the remnant of the prebranchial digestive glands, modified, or temporarily thrown out of commission, by the opening up, in this manner, of the visceral clefts (Fig. 9).

The corresponding organs of the arachnids (scorpion) are voluminous thoracic, or prebranchial, digestive glands, which in their grosser morphological relations, and in their histological structure, strongly resemble the thyroids of vertebrates.

These differences between the mouth, jaws, and gills of vertebrates and those of the arachnids are as significant, therefore, as the resemblances, and point to the same conclusion. For the peculiar conditions found in the vertebrates are seen to be the inevitable result of the conditions prevalent in the arachnids; here, as elsewhere, growth inevitably occupies the easiest paths of conveyance, and the products accumulate along the paths of least resistance.

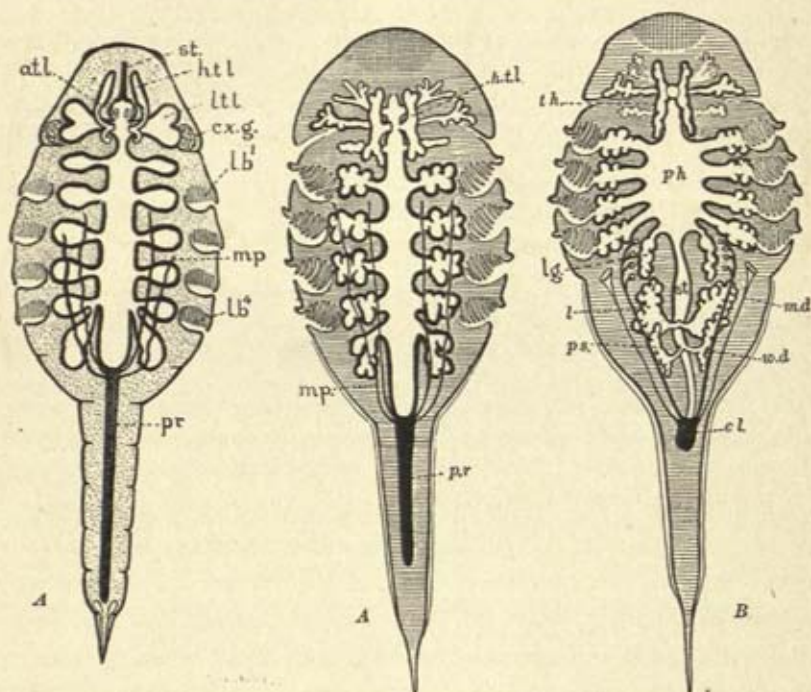


FIG. 9. Diagrams indicating the probable manner in which the arachnid gill sacs, in vertebrates, come to open into the alimentary canal. The usage of these passages for respiration prevents their usage for digestion. The anterior hæmal outgrowths, which never communicate with gill sacs, give rise to the thyroid glands. *A*, scorpion. *B*, hypothetical transition stage. *C*, vertebrate. From Patten, "The Evolution of the Vertebrates and their Kin."

In these particular cases, the forced migration of the jaws to the hæmal surface, the formation of a new mouth outside the medullary plate, and the opening of the gill sacs into the alimentary canal, result in mechanical and economic improvements of the greatest im-

portance. The great coöperative value of these improvements led to the rapid expansion and the readjustment of other organs expressed in the term evolution, and the increased rate with which these events follow one another is perhaps the chief reason for the large gap, in retrospect, between the vertebrates and their more immediate arachnid ancestors.

V.

The special cases above cited are peculiar only in the magnitude of their ensuing results. The principles involved are universal. It is because the rate of evolution and the creative value of its products vary greatly from time to time and place to place, that there is any real basis, historic and vital, for classification. It is this historic process and its sequence of causal conditions that our systems of classification tend to portray more and more fully.

Classification is not merely the arrangement of animate and inanimate things according as they are like or unlike, any more than history is a mere record of events.

Classification is history in tabloid form, and there is little value in either one or the other if they do not in some measure express the change of pace and direction of evolution and the creative value of the innovations that produced them.

There would still be great epochs in history, however complete the records might be; for the same reason, the transition from a lower class of animals to a higher one will always appear, in retrospect, as a relatively large gap, marked by the appearance of a few coöperative characters of small magnitude in themselves, but of great creative value.

A familiar example of this principle is seen in the transition from fishes to amphibia, where the chief event was the apparently insignificant enlargement and short-circuiting of one of the branchial blood vessels. This event ultimately led to the substitution of lungs for gills, and to many other changes of far reaching importance in the internal and external administration of their lives.

The four chambered heart; the hot, even tempered blood; placental nutrition; and articulate speech, are other examples of those incidental products of growth, whose appearance is epoch-making

in evolution, because of their extraordinary coöperative value and their power to create new instruments of conveyance, or to reach new sources of power.

VI.

In the administration of the outer life of the individual, the same laws of growth prevail as in the inner life. That is, group growth, or increase, in the number of individuals follows the easiest lines of conveyance (of supplies to individuals, or of individuals to supplies) and the products of growth accumulate, provincially, along the lines of least resistance.

And the individual itself is subject to the same law of coöperation as are its own internal constituents. It cannot endure except in so far as the new problems in the external administration of its life, that are raised by increase in numbers, are solved by the use of better methods of coöperation with other individuals and with the physical conditions outside itself. But the very power essential to that end is the power which is created within the individual by its methods of internal organic coöperation between muscles, and nerves, and other organs. Thus there are five principal methods of coöperation essential to the evolution of life: (1) Cosmic coöperation; (2) internal organic coöperation; (3) external coöperation of the individual with its physical surroundings; (4) external coöperation of individuals with one another (internal social coöperation); and (5) coöperation of groups, or classes, of individuals, such as plants and animals, or different nationalities, with one another (external social coöperation).

VII.

While the chief gain, result, or end in life is the perpetuation and aggrandizement of the individual unit, there are two distinct and mutually supplementary methods, in the long run, of attaining that end, namely: for the individual (1) to take all it can get, and (2) to give all it has; because thereby a larger product is attainable than can be attained by any individual alone, and because the welfare of the individual is better assured through the larger unit of which it is a coöperative part, than it is by its own unaided efforts.

Or, stated in other terms: the greater power of the individual to take what it requires is gained by using more profitable methods of internal organic coöperation. This internal power of the individual is the essential instrument for more effective external, or cosmic and social, coöperation; and it is again reinforced by giving it, or expending it, in coöperation with other individuals, for a still larger unit. The ultimate gain in this dual method of give and take is a progressive summation of organic power at the expense of inorganic and unorganized nature; and this process is progressively creative and preservative.

Thus the ultimate "interests" of the larger and of the smaller unit are identical; and the "interests" of the one and the other are alike served by the freest give and take of coöperative action; for organic evolution, or progress, is nothing else than the summation of power through the coöperative action of its constituents.

The "conflicts" in nature, which have always claimed such a large share of man's attention, are often mistaken for creative and constructive agents. The exaggeration of this tendency in recent years is an error for which the biologists themselves are largely responsible. But the one supreme truth that nature insistently teaches is that conflict and aggression are never creative forces, except in so far as destruction may serve to redistribute power so that ultimately it may be linked with other powers in better coöperative action. Evolution and progress is always measured by construction, or by the degree to which conflict decreases and coöperation increases.

The confusion of thought indicated above arises from the failure to recognize that the struggle for existence, if there is such a struggle, is a struggle to find better methods of coöperation, and the "fittest" is the thing that coöperates best.

In the larger estimate of progress, the progress of coöperative action in the inner and in the outer life of the individual, as well as in that of the great social life of nature as a whole, of which every individual is an organic part, must be given their correct, relative values; for each one of these three phases of progress is an instru-

ment to the same end, the aggrandizement and security of the whole by the part and the part by the whole.

From this larger point of view, what we call "evil" is that which prevents or destroys coöperation, and "good" is that which perpetuates and improves coöperation. Evolution in nature, as a whole, proceeds with the attainment of righteousness, or as fast as the better ways of avoiding that which is evil and of attaining that which is good, are found by the part and by the whole.

As the animal and plant life of the world becomes more complex individually, and more unified as a whole, the necessity for wider and better coöperation in exchange becomes more imperative; or to put it another way, life at large, individually and in its various aggregates, grows in unity and in the summation of power, as fast as it finds and makes use of better methods of conveyance for mutually profitable exchange, or creates new instruments to that end.

In the inorganic world, and in the lower phases of organic life, the right way to coöperative action is found by "chance," during a prolonged period of trial and error. It is a slow process, but inevitably accumulative and accelerative, for there is a directive and preservative element, a tendency towards finality and completion, in coöperative action, that is none the less effective whether it be found by accident or by design. In the higher phases of individual life, the more elaborate series of preservative and coöperative acts are called "instincts and intelligence." The chief element in "intelligence" is the power to foresee and to select the better time and place for coöperative action, thereby greatly accelerating the process of attaining good and avoiding evil.

VIII.

The same laws that govern the growth of plants and of animals, govern the growth of human society. Society in its growth follows the easiest and most accessible lines of conveyance; and its rate of growth depends on the coöperative value of its inventions for the preservation and profitable exchange of its own products, intellectual or physical. Science, literature, and art, are the reservoirs and distributing channels for the one, and commerce for the other.

They are the agents produced by growth that supply the demands of growth, and the profits of this exchange will provide the new means for supplying the new demands.

Need it be said that the chief function of statesmanship is to keep these social reservoirs full and the channels of exchange open; and to find better methods of coöperative action between individuals, states, and empires, in order better to meet the new problems in the give and take of commodities that arise with the growth of the individual and of his various social groups?

A DYNAMICAL THEORY OF ANTAGONISM.

By W. J. V. OSTERHOUT.

(Read April 14, 1916.)

When toxic substances act as antidotes to each other we call this action antagonism. The writer has found that an accurate measure of antagonism is furnished by the electrical resistance of living tissues. A toxic substance causes a fall of resistance: but if another toxic substance be added and the fall of resistance be thereby inhibited it is evident that this result is due to antagonism. The amount of antagonism may therefore be measured by the fall of resistance.

A series of such measurements is reported in the present paper.¹ The method of making these measurements has been previously described.²

The experiments consisted in determining the electrical resistance of *Laminaria Agardhii*³ in NaCl .52 M, in CaCl₂ .278 M and in various mixtures of these.

In order that each solution might contain as nearly as possible the same kind of material the following method was employed. Seven disks were cut (by means of a large cork borer) from the same part of a frond: each disk was placed in a separate tumbler of sea water. A second lot of seven disks were cut, as close to each other as possible, and placed in the tumblers, so that each tumbler contained two disks. This was continued until each tumbler con-

¹ In an earlier series (Pringsheim's *Jahrb. für wiss. Bot.*, 54: 645, 1914) the maximum antagonism was found in mixtures containing less NaCl than is here reported. The present series comprises six sets of experiments (in the earlier there were only three), was made at more nearly constant temperature and with an improved technique. The later results may therefore be regarded as more reliable.

² *Science*, N. S., 35: 112, 1912.

³ This is the most common species at Wood's Hole, Mass.; it was formerly identified as *L. saccharina* and is so referred to in earlier papers by the writer.

tained one hundred disks. By this means the material in the different tumblers was made as similar as possible. The disks in each tumbler were then packed together (like a roll of coins) to form a cylinder whose resistance was measured. Throughout the experiments the different lots were kept side by side and treated as nearly alike as possible, except that they were placed in different solutions.

Great care was taken that all the solutions (both pure and mixed) should have the same conductivity as sea water.

The distilled water used in making the solutions was prepared with especial care, the first and last part of the distillate being discarded. It was distilled from a glass still (which had been used for some months) using plugs of cotton in place of cork or rubber stoppers.

The salts used were the purest obtainable, being for the most part Kahlbaum's (in some cases Merck's blue label reagents were employed).

The mixtures were made in the following proportions:

NaCl .52 <i>M</i> , c.c.	CaCl ₂ .278 <i>M</i> , c.c.	Molecular Proportions.	
		NaCl.	CaCl ₂ .
963	37	98	2
914	86	95.24	4.76
751	249	85	15
496	504	65	35
247	753	38	62

The results⁴ are shown graphically in Fig. 1 (cf. Table III.). As will be seen on inspection of the figure, the resistance rises at first (except in pure NaCl) and subsequently falls.

Evidently two processes are involved, one of which produces a rise, the other a fall in resistance. While these processes might be looked upon as independent, everything points to the fact that they are casually connected, and it seems natural to assume that they represent two chemical reactions, one of which is dependent on the other.

⁴ The results are expressed as per cent. of the net resistance in sea water at the start of the experiment. They might also be expressed as per cent. of the control but this has no especial advantage for the present investigation.

We may suppose for the sake of simplicity that they represent two monomolecular reactions⁵ of the type

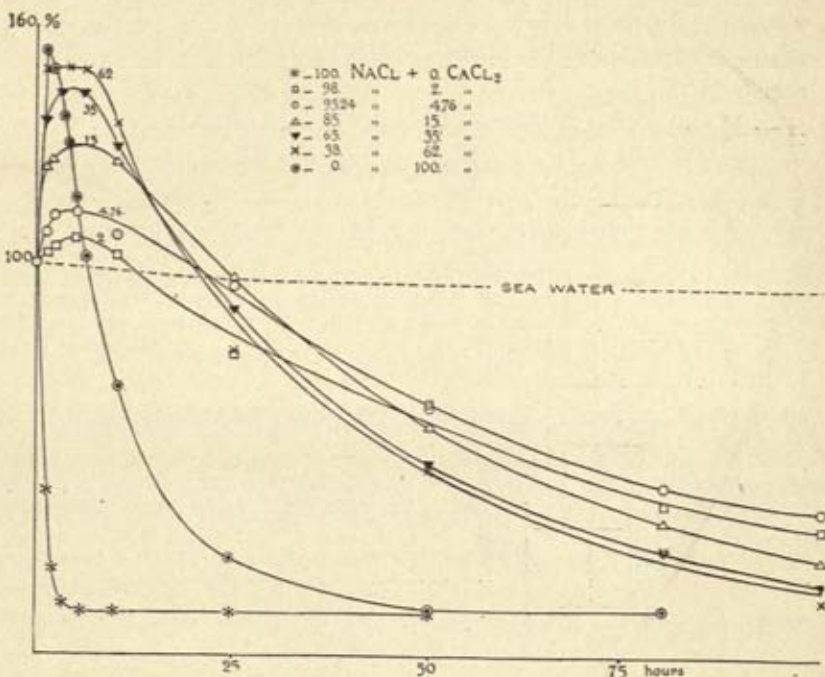
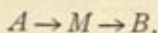


FIG. 1. Curves of electrical resistance of *Laminaria* in NaCl .52 *M*, in CaCl₂ .278 *M*, and in mixtures of these (the figures show the molecular per cent. of CaCl₂ in the mixture). Some points are omitted in order to avoid undue crowding (these may be obtained from Table III).

in which a substance *A* breaks down into an intermediate substance *M* which in turn breaks down to form *B*. In such a reaction the amount of *M* at first increases, reaches a maximum and then decreases.

The nature of this process is evident from a consideration of Fig. 2. If the reservoir *A* be filled with water while *M* and *B* are empty, and if water be allowed to flow from *A* into *M*, the amount of water in *M* (for convenience this amount is called *y*) will first

⁵ Or other reactions of the first order as for example when two substances react but one is present in great excess.

increase and then decrease. The rate of increase and decrease and the maximum attained will depend on the relation between the two outlets K_1 and K_2 . We may suppose that if K_1 is equal to K_2 we get the upper curve shown in the figure, while if K_1 is less than K_2 we get the lower curve (in the latter case both constants are supposed to be smaller than in the former). This is analogous to what occurs in the reaction $A \rightarrow M \rightarrow B$ if K_1 is the velocity constant of $A \rightarrow M$ and K_2 is the velocity constant of $M \rightarrow B$.

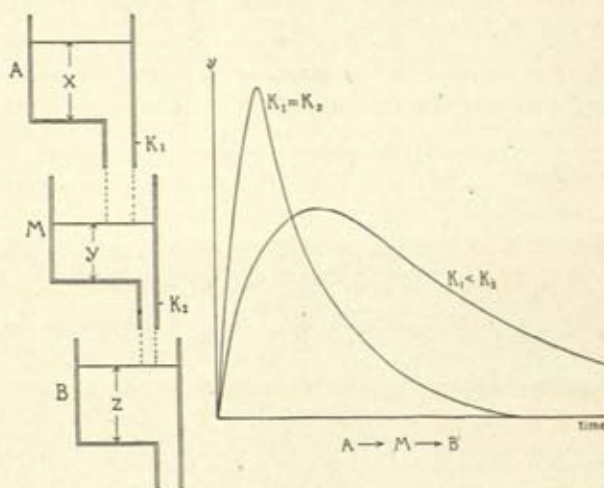


FIG. 2. Diagram illustrating consecutive reactions in which a substance M is formed by the reaction $A \rightarrow M$ and decomposed by the reaction $M \rightarrow B$. Explanation in text.

We find that the resistance of the tissue likewise increases to a maximum and then decreases. If we assume that the resistance of the protoplasm is due to a substance⁶ M we can calculate the rate at which the resistance will increase and decrease with any given values of K_1 and K_2 .

If we suppose that in sea water the substance M results from the decomposition of A , which is in turn formed at a constant rate, the amount of M will be constant (after equilibrium has once been

⁶ Instead of a substance we might assume that M is a physical state or a mixture provided it fulfilled the necessary conditions of formation and disappearance.

attained). For convenience we assume that at equilibrium the concentration of M (which we call y) is equal to 0.2951 and that the net resistance (expressed as per cent. of the net resistance in sea water) is equal to $305y + 10$, the 10 being added because at death the resistance drops to 10 per cent. (i. e., the resistance of the dead tissue is 10 per cent. of that of the living). The resistance in sea water will therefore be $(.2951 \times 305) + 10 = 100$ per cent.

Let us assume that the velocity constant of the decomposition of M in sea water is .540. If the velocity constant of the reaction $A \rightarrow M$ is one thirtieth as great ($.540 \div 30 = .018$) the concentration of A must be 30 times as great as that of M in order to keep M constant. Hence the concentration of A (which will be called x) must be $.2951 \times 30 = 8.853$.

On transferring from sea water to such a mixture as 65 NaCl + 35 CaCl₂ we assume that the production of A ceases while the decomposition of A and M go on at an altered rate, the velocity constant for $A \rightarrow M$ being changed to .000481 and that of $M \rightarrow B$ to .00859. We can now calculate the value of y at any subsequent time, T .

The value of y at the start is .2951 and this will decrease (by the ordinary monomolecular formula) in the time T to

$$y = .2951(e^{-K_2 T}).$$

In this formula e is the basis of natural logarithms and K_2 is the velocity constant of the reaction $M \rightarrow B$, which results in the decomposition of y .

The value of x at the start is 8.853: this will produce during the time T a certain amount of y part of which will be decomposed. The amount remaining at the end of the time T is given by the formula[†]

$$y = .8.853 \left(\frac{K_1}{K_2 - K_1} \right) (e^{-K_1 T} - e^{-K_2 T}),$$

[†] Rutherford, E., "Radioactive Substances and their Radiations," 1913, p. 421. The values $e^{-K_1 T}$ and $e^{-K_2 T}$ may be obtained from Table IV. in the Smithsonian Mathematical Tables, Hyperbolic Functions, by G. F. Becker and C. E. Van Orstrand, 1909. See also Mellor, J. W., "Chemical Statics and Dynamics, 1909, pp. 16, 98, 118.

in which K_1 is the velocity constant of the reaction $A \rightarrow M$. The total value of y at the time T will be

$$y = .2951(e^{-K_2 T}) + 8.853 \left(\frac{K_1}{K_2 - K_1} \right) (e^{-K_1 T} - e^{-K_2 T}).$$

If we put $K_1 = .000481$ and $K_2 = .00859$ we obtain as the amount of resistance the values given in Table III. and plotted as a broken line in Fig. 3 (the values obtained experimentally are plotted as a continuous line).

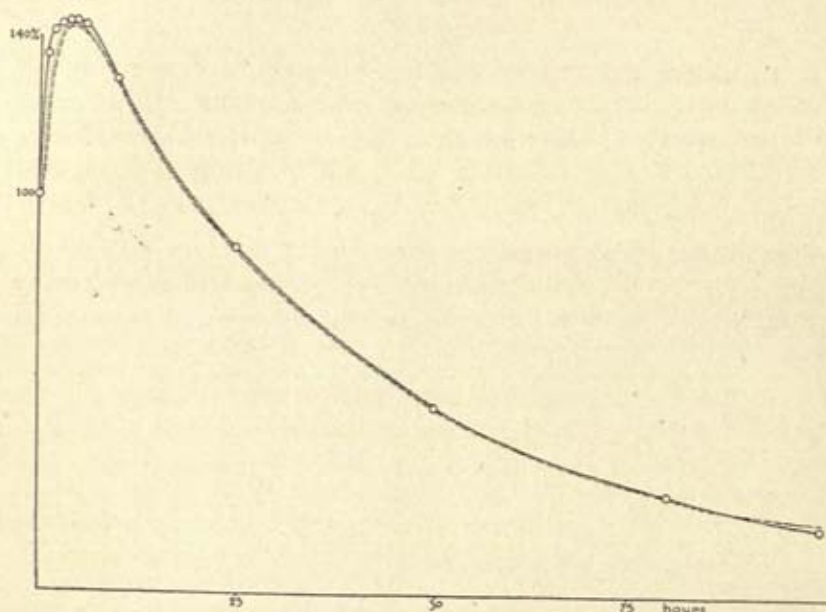


FIG. 3. Curve of electrical resistance of *Laminaria* in 65 NaCl + 35 CaCl₂ (—), the trial curve (---) calculated from the velocity constants $K_1 = .000481$ and $K_2 = .00859$, and the theoretical curve (.....) calculated from the velocity constants $K_1 = .000482$ and $K_2 = .00859$.

Evidently the curve of resistance,⁸ as calculated, agrees⁹ fairly

⁸ The agreement in other mixtures may be seen in Table III. and Figs. 6-9.

⁹ The fact that the theoretical curves can not be made to assume any desired form but can only be varied within certain limits shows that if they fit the experimental curves they express processes similar to those which take place in the tissue.

well with the curve of resistance in 65 NaCl + 35 CaCl₂ obtained experimentally.

We see that in 65 NaCl + 35 CaCl₂ the resistance of the tissue behaves as if it were directly proportional to y (the amount of M) when the velocity constant of $A \rightarrow M$ is .000481 and the velocity constant of $M \rightarrow B$ is .00859. We may interpret this to mean that some substance, A , in the protoplasm breaks down to form M , the substance to which the resistance of the protoplasm is due, and this is in turn decomposed, the two reactions having the velocities indicated.

By making this very reasonable assumption we can account for all the curves of resistance obtained experimentally.

In order to see how this may be accomplished we may calculate the constants of all the curves, proceeding in the same manner as in calculating the constants of the curve of 65 NaCl + 35 CaCl₂. For this purpose we assume various values until the correct ones are discovered. The values obtained by this method are given in Table I.

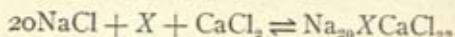
TABLE I.
RELATION OF K_2 TO $\text{Na}_2\text{XCaCl}_4$.
Constants obtained by trial.

Molecular Proportions.				Amount of $\text{Na}_2\text{XCaCl}_4$.	Increase of $\text{Na}_2\text{XCaCl}_4$.	K_1 .	K_2 .	Decrease of K_2 .	(Decrease of K_2) + (Increase of $\text{Na}_2\text{XCaCl}_4$).
In Body of Solution.		In Surface.							
NaCl. %.	CaCl ₂ . %.	NaCl. %.	CaCl ₂ . %.						
98	2	83.05	16.95	.0001169	.0001137	.000253	.00672	.00228	19.35
95.24	4.76	66.67	33.33	.0001468	.0001436	.000245	.00590	.00310	21.59
85	15	36.27	63.73	.0000839	.0000807	.000364	.00730	.00170	21.07
65	35	15.66	84.34	.0000207	.0000175	.000481	.00859	.00041	23.43
38	62	5.78	94.22	.0000032		.000530	.00900		
100	0					.018	.540		
0	100					.0018	.0295		

An inspection of Table I. shows that as the amount of CaCl₂ increases, the value of K_2 first falls and then rises, the minimum value occurring at 95.24 NaCl + 4.76 CaCl₂ (which is the mixture in which the tissue lives longest). It is evident that in each mixture of NaCl + CaCl₂ a substance is formed which in some way reduces

the value of K_2 . We may assume that the amount of this substance increases as CaCl_2 increases and that its maximum effect on K_2 is produced in $95.24 \text{ NaCl} + 4.76 \text{ CaCl}_2$, after which a further increase of this substance produces less and less effect on K_2 . Or we may assume that the decrease of K_2 is directly proportional to the amount of this substance but that the maximum amount of this substance is produced in $95.24 \text{ NaCl} + 4.76 \text{ CaCl}_2$, while in other mixtures it is produced in lesser amounts. Let us consider more fully the latter alternative.

The simplest assumption which we can make is that both NaCl and CaCl_2 combine with some substance, X , in the protoplasm so as to form a compound. If we suppose that this compound¹⁰ is $\text{Na}_{20}\text{XCaCl}_{22}$ formed by the reversible reaction



we can calculate the amount of $\text{Na}_{20}\text{XCaCl}_{22}$ which will be formed in each mixture of $\text{NaCl} + \text{CaCl}_2$.

The molecular concentration of X can hardly be more than a small fraction of that of NaCl and CaCl_2 . Hence as NaCl and CaCl_2 are present in great excess they may be regarded as constant in concentration and we need only consider the changes in X and $\text{Na}_{20}\text{XCaCl}_{22}$.

We may calculate the amounts of $\text{Na}_{20}\text{XCaCl}_{22}$ formed at equilibrium in any mixture by means of the formula

$$K = \frac{\text{Conc}_{\text{Na}_{20}\text{XCaCl}_{22}}}{(\text{Conc}_{\text{NaCl}})^{20}(\text{Conc}_{\text{CaCl}_2})(\text{Conc}_X)},$$

in which K is a constant and the molecular concentrations of $\text{Na}_{20}\text{XCaCl}_{22}$, NaCl , CaCl_2 , and X are denoted by the abbreviation *Conc.* We find that the amount of $\text{Na}_{20}\text{XCaCl}_{22}$ begins with 0 in pure NaCl , increases with the increase of CaCl_2 until it reaches a maximum at $\text{NaCl } 95.24 + \text{CaCl}_2 \text{ } 4.76$ and then decreases (as CaCl_2 continues to increase) until it falls to 0 in pure CaCl_2 . As this is exactly what K_2 does, we might assume that $\text{Na}_{20}\text{XCaCl}_{22}$ acts as a negative catalyzer, causing a decrease in K_2 which is directly proportional to the amount of $\text{Na}_{20}\text{XCaCl}_{22}$.

¹⁰ Such compounds are frequently formed between salts and proteins as well as with many other amphoteric electrolytes.

To this however there is the objection that the maximum amount of $\text{Na}_{20}\text{XCaCl}_{22}$ which is produced in $\text{NaCl } 95.24 + \text{CaCl}_2 4.76$ could also be obtained in other mixtures, *e. g.*, in $\text{NaCl } 50 + \text{CaCl}_2 50$ if the total concentration of salts in the latter mixture were increased to the requisite amount. This is contrary to what we find in antagonism experiments. If antagonism really depends on the production of a salt compound like $\text{Na}_{20}\text{XCaCl}_{22}$ it is evident that some mechanism must exist which insures that an increase in the total concentration of salts can have but little effect as compared with that produced by a change in their relative proportions.

It is easy to see how such a mechanism must exist if the formation of $\text{Na}_{20}\text{XCaCl}_{22}$ takes place at a surface (at the external surface of the cell or at internal surfaces). In a surface substances usually exist in a different concentration from that which they have elsewhere in the solution. If NaCl and CaCl_2 migrate into the surface, so as to become more concentrated there than in the rest of the solution, their concentration in the surface must increase as their concentration in the solution increases until a certain point (called the saturation point) is reached. Beyond this point an increase in their concentration in the solution produces no effect on their concentration in the surface.

When this stage has been reached the formation of $\text{Na}_{20}\text{XCaCl}_{22}$, if it takes place in the surface, will not be affected by an increase in the concentration of the salts in the solution. It will, however, be affected by changes in the relative proportions of the salts. The number of molecules of salt in a unit of surface will remain nearly constant, but if the proportion of NaCl in the solution be increased some of the CaCl_2 in the surface will be displaced by NaCl .

Below the saturation point the relative proportions of the salts will be of less importance than their total concentration: this is the case at low concentrations in the region of the so-called "nutritive effects."

It may be added that these considerations apply no matter whether the salts which migrate into the surface come from the outside or from within (or from both directions): also that they apply when the surface is completely permeable to salts (so that we do not assume an impermeable surface in order to account for

the formation of the salt compound which itself accounts for the permeability). They also apply if $\text{Na}_{20}\text{XCaCl}_{22}$ is formed elsewhere than at the surface and subsequently migrates into the surface for, as the reaction is reversible, the equilibrium in the surface must be determined by the amounts of X , NaCl , and CaCl_2 , regardless of whence they are derived.

Let us consider what will happen if NaCl and CaCl_2 do not migrate equally into the surface. If for example CaCl_2 accumulates in the surface ten times as much¹¹ as NaCl we shall have in the surface $\text{NaCl } 2 + \text{CaCl}_2 \text{ } 1$ when the body of the solution contains $\text{NaCl } 20 + \text{CaCl}_2 \text{ } 1$ (or $\text{NaCl } 95.24 + \text{CaCl}_2 \text{ } 4.76$).

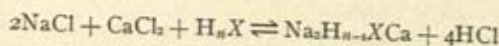
Let us assume that this is the case and that the salt compound formed is not $\text{Na}_{20}\text{XCaCl}_{22}$ but $\text{Na}_2\text{XCaCl}_4$. Its maximum amount will be produced when the solution contains $\text{NaCl } 20 + \text{CaCl}_2 \text{ } 1$ or $\text{NaCl } 95.24 + \text{CaCl}_2 \text{ } 4.76$ and will be independent of the total concentration of salts so long as the surface is saturated. We may calculate the amounts present in the surface according to the formula.¹²

$$K = \frac{\text{Conc}_{\text{Na}_2\text{XCaCl}_4}}{(\text{Conc}_{\text{NaCl}})^2(\text{Conc}_{\text{CaCl}_2})(\text{Conc}_X)}.$$

When we have $\text{NaCl } 95.24 + \text{CaCl}_2 \text{ } 4.76$ in the solution we have in the surface $\text{NaCl } 9.524 + \text{CaCl}_2 \text{ } 4.76$ or $\text{NaCl } 66.67$ per cent. + $\text{CaCl}_2 \text{ } 33.33$ per cent.; and since they are present in excess this will

¹¹ There is experimental evidence in favor of the view that CaCl_2 accumulates in the surface more than NaCl .

¹² If we write



we have at equilibrium

$$K = \frac{(\text{Conc}_{\text{Na}_2\text{H}_{n-4}\text{XCa}})(\text{Conc}_{\text{HCl}})^4}{(\text{Conc}_{\text{NaCl}})^2(\text{Conc}_{\text{CaCl}_2})(\text{Conc}_{\text{H}_n\text{X}})}$$

but

$$\text{Conc}_{\text{HCl}} = 4(\text{Conc}_{\text{Na}_2\text{H}_{n-4}\text{XCa}})$$

so that we may write

$$K = \frac{(\text{Conc}_{\text{Na}_2\text{H}_{n-4}\text{XCa}})^5}{(\text{Conc}_{\text{NaCl}})^2(\text{Conc}_{\text{CaCl}_2})(\text{Conc}_{\text{H}_n\text{X}})}.$$

In the present case this assumption does not fit the facts as well as the one already made.

be their concentration at equilibrium (as well as during the progress of the reaction). Putting $K = .000001$ and $\text{Conc}_X = .001$ we get

$$.000001 = \frac{\text{Conc}_{\text{Na}_2\text{XCaCl}_4}}{(66.67)^2(33)(.001)},$$

whence

$$\text{Conc}_{\text{Na}_2\text{XCaCl}_4} = .0001468.$$

Calculating the amounts formed in other mixtures we get the values given in Table I.

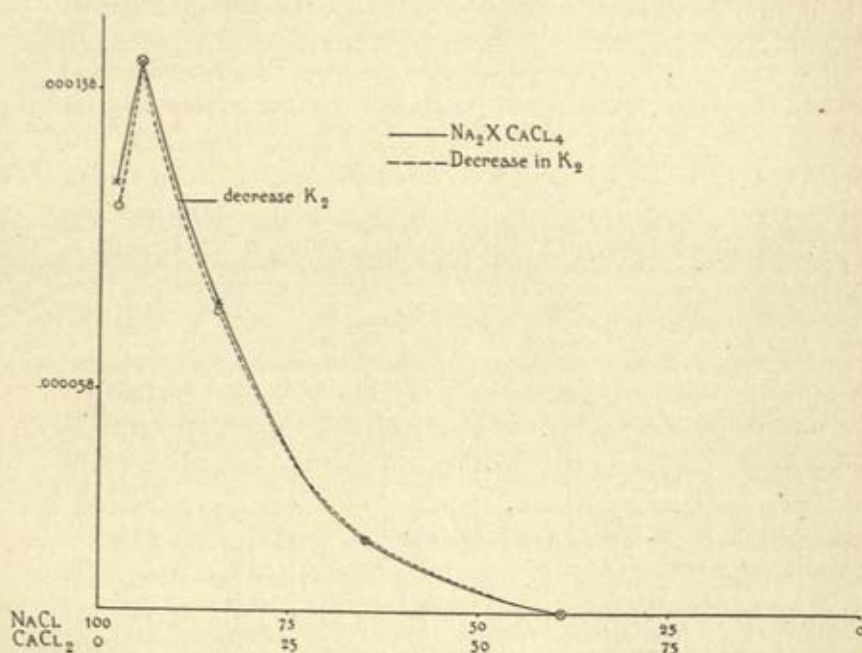


FIG. 4. Curve of the increase of a salt compound, $\text{Na}_2\text{XCaCl}_4$ (—), and curve of the decrease of the velocity constant K_2 (---). The figures apply to the ordinates of the former curve. The figures for the ordinates of the latter curve (---) are 21.59 times as great. The abscissæ represent molecular proportions in the solution (not in the surface). The figure shows that the salt compound inhibits the reaction $M \rightarrow B$ (which has the velocity constant K_2).

It is evident from an inspection of the last column of Table I. that the decrease in K_2 is directly proportional to the amount of

$\text{Na}_2\text{XCaCl}_4$ (see Fig. 4).¹³ Hence we assume that $\text{Na}_2\text{XCaCl}_4$ acts as a negative catalyzer to the reaction $M \rightarrow B$.

In some instances the optimum proportion in antagonism experiments turns out to be $\text{NaCl } 100 + \text{CaCl}_2 \text{ } 1$. In this case we should, following the course just outlined, assume that the salt compound is $\text{Na}_{10}\text{XCaCl}_{12}$. It may be objected that this calls for a reaction of a high order, the occurrence of which seems not very probable. But it must be remembered that the reaction may take place by a series of steps each of which represents a reaction of the second or third order. Such cases are well known in inorganic chemistry. In the calculations all these steps may be disregarded since only the final equilibrium need be considered.

An inspection of Table I. shows that the value of K_1 rises and falls with that of K_2 except that as CaCl_2 increases the value of K_1 goes up more rapidly than that of K_2 . This is also obvious from Fig. 1, which shows that the greater the per cent. of CaCl_2 in the mixture the greater the maximum attained. As this maximum de-

TABLE II.
RELATION BETWEEN $(K_1 \div K_2)$ AND PER CENT. OF CaCl_2 IN SURFACE.
Constants obtained by trial.

Molecular Proportions.				K ₁ .	K ₂ .	K ₁ + K ₂ .	Increase of K ₁ + K ₂ .	(Increase of K ₁ + K ₂) ÷ (Per Cent. of CaCl ₂ in Surface).
In Solution.		In Surface.						
NaCl.	CaCl ₂ .	NaCl.	CaCl ₂ .					
100	0	100	0	.018	.540	.03333		
98	2	83.05	16.95	.000253	.00672	.03765	.00432	.000255
95.24	4.76	66.67	33.33	.000245	.00590	.04153	.00820	.000246
85	15	36.27	63.73	.000364	.00730	.04986	.01653	.000259
65	35	15.66	84.34	.000481	.00859	.05600	.02267	.000269
38	62	5.78	94.22	.000530	.00900	.05889	.02556	.000271
0	100	0	100	.0018	.0295	.06102	.02769	.000277

pend on the value of $K_1 \div K_2$ it is obvious that the value of $K_1 \div K_2$ must increase as the per cent. of CaCl_2 increases. We therefore assume that the value of K_1 (like that of K_2) depends on the amount of $\text{Na}_2\text{XCaCl}_4$ but that (unlike that of K_2) it is also

¹³ The figure makes the curve of $\text{Na}_2\text{XCaCl}_4$ bend more abruptly at the apex than is actually the case, but it is so drawn because it is not desirable to use more points in the calculated than in the experimental curve.

dependent on the per cent. of CaCl_2 present in the surface. If this assumption is correct the value of $K_1 \div K_2$ will be proportional to the per cent. of CaCl_2 . This is actually the case, as is evident from Table II. and Fig. 5.

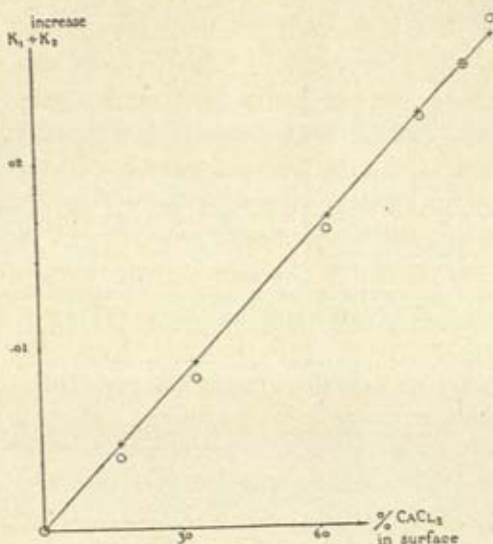


FIG. 5. Curve of the increase of $K_1 \div K_2$ with increase of CaCl_2 (molecular per cent. in the surface). The figure shows that CaCl_2 acts as a catalyzer of the reaction $A \rightarrow M$ (which has the velocity constant K_1).

We must therefore conclude that the reaction $A \rightarrow M$ is catalyzed by CaCl_2 , while the salt compound $\text{Na}_2\text{XCaCl}_4$ inhibits both $A \rightarrow M$ and $M \rightarrow B$. This assumption enables us to calculate the resistance at any time in any mixture. The calculated results are given in Table III. together with the observed values. The calculations are made on the assumption that the decrease of K_2 is exactly proportional to the increase of $\text{Na}_2\text{XCaCl}_4$, that is

$$\frac{\text{decrease of } K_2}{\text{increase of } \text{Na}_2\text{XCaCl}_4} = 23.29$$

and

$$\frac{\text{increase of } (K_1 \div K_2)}{\text{per cent. } \text{CaCl}_2 \text{ in surface}} = .000271.$$

TABLE III.

OBSERVED VALUES COMPARED WITH VALUES CALCULATED ON A THEORETICAL BASIS.

Time in Hours.	Per Cent. of Net Resistance in									
	98 NaCl + 2 CaCl ₂ .		95.24 NaCl + 4.76 CaCl ₂ .		85 NaCl + 15 CaCl ₂ .		65 NaCl + 35 CaCl ₂ .		38 NaCl + 62 CaCl ₂ .	
	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
1	103.1	103.7	108.2	106.8	124.5	115.6	136.1	123.8	148.1	127.2
2	103.8	105.8	112.1	111.2	126.1	124.8	141.9	136.3	149.0	141.7
3	105.8	106.7	112.1	113.8	128.5	129.8	143.2	142.2	149.0	147.9
4	106.1	106.9	113.9	115.3	130.2	132.1	143.9	144.0	149.0	149.7
5	106.1	106.6	113.1	115.8	130.2	132.7	143.9	143.6	149.0	148.8
6	104.9	106.0	113.1	115.8	130.2	132.3	143.7	141.7	149.0	146.5
10	102.1	101.8	107.9	112.5	126.5	125.1	129.5	129.8	136.1	132.6
25	76.89	84.21	95.21	93.41	96.40	93.80	87.85	87.90	78.21	86.30
50	63.90	61.70	62.50	68.20	58.11	58.83	47.81	47.80	46.34	44.46
80	38.90	43.49	42.52	47.78	33.92	35.54	26.01	25.88	27.11	23.27
100	31.80	35.09	35.83	38.33	24.01	26.58	17.33	18.90	14.42	17.03

The measurements were made at 15° C. or corrected to this figure. Each experimental figure is the average obtained from 6 series of experiments.

The constants obtained by this method of calculation are given in Table IV.

Table III. shows that the agreement between calculated and observed values is remarkably satisfactory.

TABLE IV.

THEORETICAL CONSTANTS.

Molecular Proportions.				K ₁ .	K ₂ .
In Solution.		In Surface.			
NaCl.	CaCl ₂ .	NaCl.	CaCl ₂ .		
100	0	100	0	.018	.540
98	2	83.05	16.95	.000241	.00635
95.24	4.76	66.67	33.33	.000240	.00566
85	15	36.27	63.73	.000360	.00712
65	35	15.66	84.34	.000482	.00859
38	62	5.78	94.22	.000530	.00900
0	100	0	100	.0017827	.0295

If we disregard all theoretical considerations and proceed by repeated trials to find what constants most nearly fit the experimental curves we get the values given in Table I. If we construct curves using these constants we get the results given in Table V.

In Fig. 3 and in Figs. 6-9 are shown curves expressing the observed values, the values calculated from constants observed by trial and the values calculated on a theoretical basis.

TABLE V.
OBSERVED VALUES COMPARED WITH VALUES CALCULATED FROM CONSTANTS
OBTAINED BY TRIAL.

Time in Hours.	Per Cent. of Net Resistance in											
	NaCl.		$\frac{98}{2} \text{ NaCl}$ + $\frac{1}{2} \text{ CaCl}_2$		$\frac{95.24}{4.76} \text{ NaCl}$ + $\frac{1}{4.76} \text{ CaCl}_2$		$\frac{86}{15} \text{ NaCl}$ + $\frac{1}{15} \text{ CaCl}_2$		$\frac{65}{35} \text{ NaCl}$ + $\frac{1}{35} \text{ CaCl}_2$		$\frac{38}{62} \text{ NaCl}$ + $\frac{1}{62} \text{ CaCl}_2$	
	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
1	40.21	41.62	103.1	103.6	108.2	106.3	124.5	115.3	136.1	123.7	148.1	127.2
2	22.82	20.74	103.8	105.6	112.1	110.3	126.1	124.1	141.9	136.2	149.0	141.7
3	14.54	13.65	105.8	106.3	112.1	112.6	128.5	128.8	143.2	141.9	149.0	147.9
4	11.28	11.24	106.1	106.3	113.9	113.8	130.2	130.9	143.9	143.8	149.0	149.7
5	10.30	10.43	106.1	105.8	113.1	114.1	130.2	131.3	143.9	143.3	149.0	148.8
6			104.9	105.0	113.1	113.0	130.2	130.6	143.7	141.5	149.0	146.5
10			102.1	100.5	107.9	110.2	126.5	123.3	139.5	120.6	136.1	132.6
25			76.89	82.28	95.21	91.00	96.40	92.08	87.85	87.84	78.21	86.30
50			63.90	59.45	62.50	66.08	58.11	57.55	47.81	47.83	46.34	44.46
80			38.90	41.36	42.52	46.09	33.92	34.60	26.01	25.92	27.11	23.27
100			31.80	33.15	35.83	36.90	24.01	25.96	17.33	18.94	14.42	17.03

The measurements were made at 15° C. or corrected to this figure. Each experimental figure is the average obtained from 6 series of experiments.

In Table V. the calculated values necessarily show a better agreement with observed values than those in Table III., but even in the latter the difference between calculated and observed values is surprisingly small. The closeness of the agreement furnishes the most

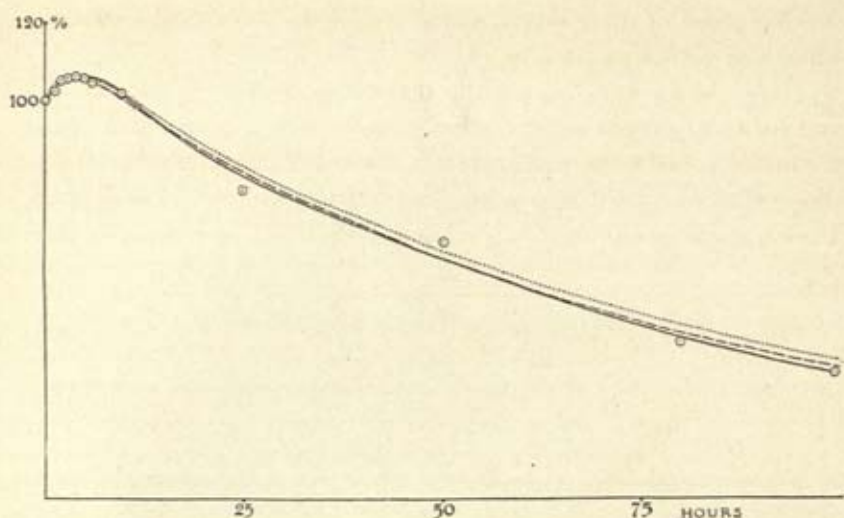


FIG. 6. Curve of electrical resistance of *Laminaria* in 98 NaCl + 2 CaCl₂ (—), the trial curve (---) calculated from the velocity constants $K_1 = .000253$ and $K_2 = .00672$, and the theoretical curve (.....), calculated from the velocity constants .000241 and .00635.

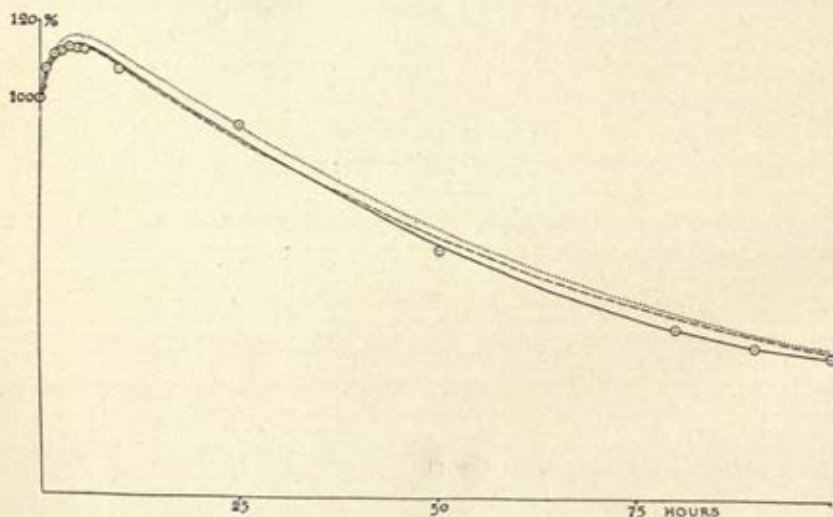


FIG. 7. Curve of electrical resistance of *Laminaria* in 95.24 NaCl + 4.76 CaCl₂ (—), the trial curve (---) calculated from the velocity constants $K_1 = .000245$ and $K_2 = .00590$, and the theoretical curve (.....) calculated from the velocity constants $K_1 = .000240$ and $K_2 = .00566$.

striking proof of the essential soundness of the theoretical views on which the calculations are based.

It should be noted that while the values of $K_1 \div K_2$ for NaCl and for CaCl_2 fit the general scheme, the absolute values of K_1 and K_2 in these cases are much greater than we should expect. This shows that in pure CaCl_2 something accelerates both $A \rightarrow M$ and $M \rightarrow B$ to an equal degree (*i. e.*, multiplies both K_1 and K_2 by the

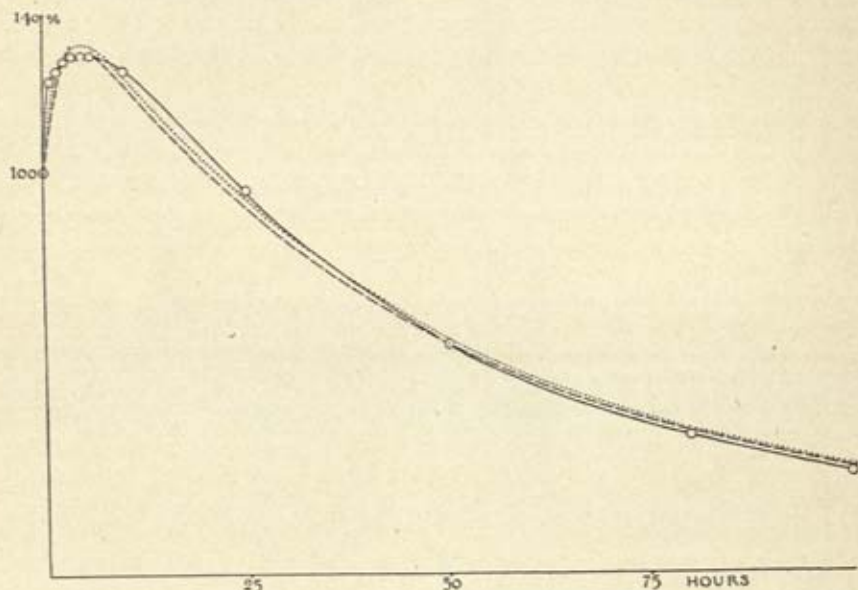


FIG. 8. Curve of electrical resistance of *Laminaria* in 85 NaCl + 15 CaCl_2 (—•—), the trial curve (— — — —) calculated from the velocity constants $K_1 = .000364$ and $K_2 = .00730$, and the theoretical curve (.....) calculated from the velocity constants $K_1 = .000360$ and $K_2 = .00712$.

same factor); the same is true of NaCl, but here the acceleration is much greater than in CaCl_2 . This acceleration might be due to a variety of causes and it seems unnecessary to discuss it more fully at this time.

Figs. 10 and 11 show the curves of resistance in NaCl and in CaCl_2 and the curves calculated from constants obtained by trial.

Let us now consider briefly an alternative explanation of these results.

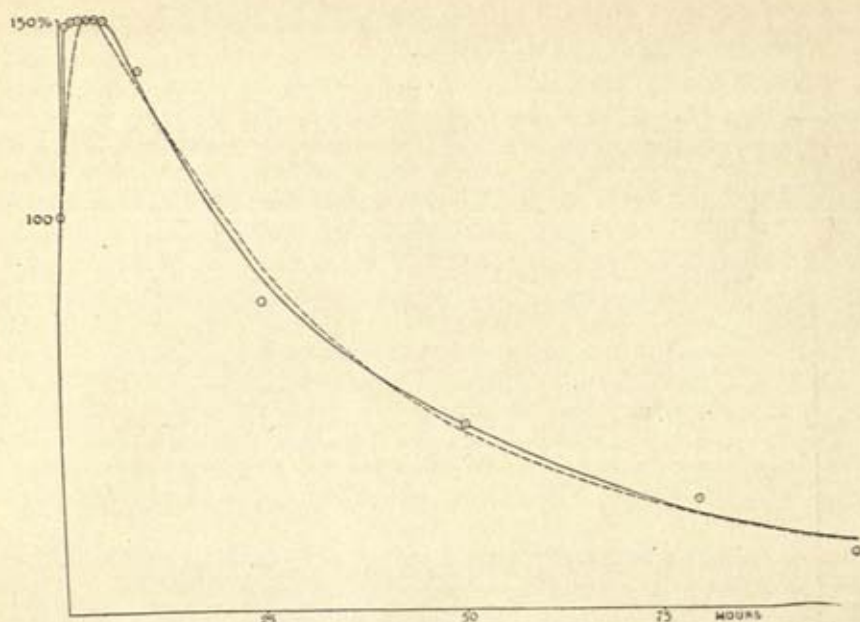


FIG. 9. Curve of electrical resistance of *Laminaria* in 38 NaCl + 62 CaCl₂ (—), and the trial curve (----) calculated from the velocity constants $K_1 = .000530$ and $K_2 = .0090$.

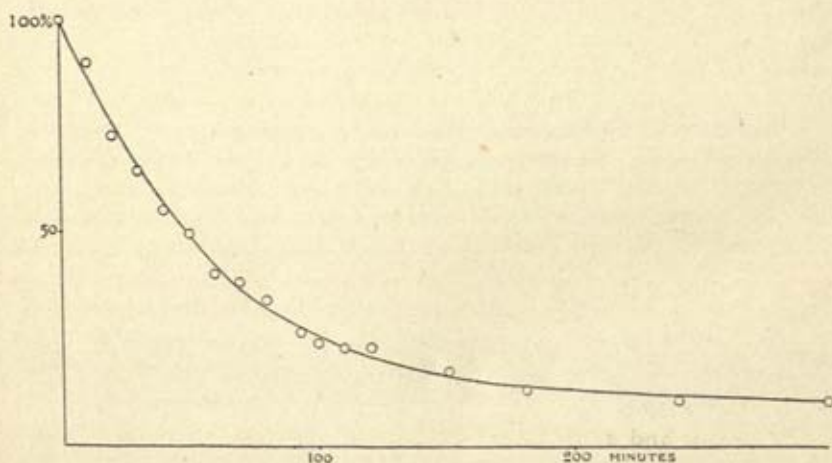


FIG. 10. Curve of electrical resistance of *Laminaria* in NaCl (.....), and the trial curve (——) calculated from the velocity constants $K_1 = .018$ and $K_2 = .540$.

It might be assumed that no salt compound is formed but that K_1 is increased by CaCl_2 and that the effect is at a minimum at $\text{NaCl } 95.24 + \text{CaCl}_2 \text{ } 4.76$. In this case K_1 would be very large in pure NaCl , very small in $\text{NaCl } 95.24 + \text{CaCl}_2 \text{ } 4.76$ (or thereabouts) and would steadily increase as the proportion of Ca increased. If K_2 is increased by NaCl , with a minimum at $\text{NaCl } 95.24 +$

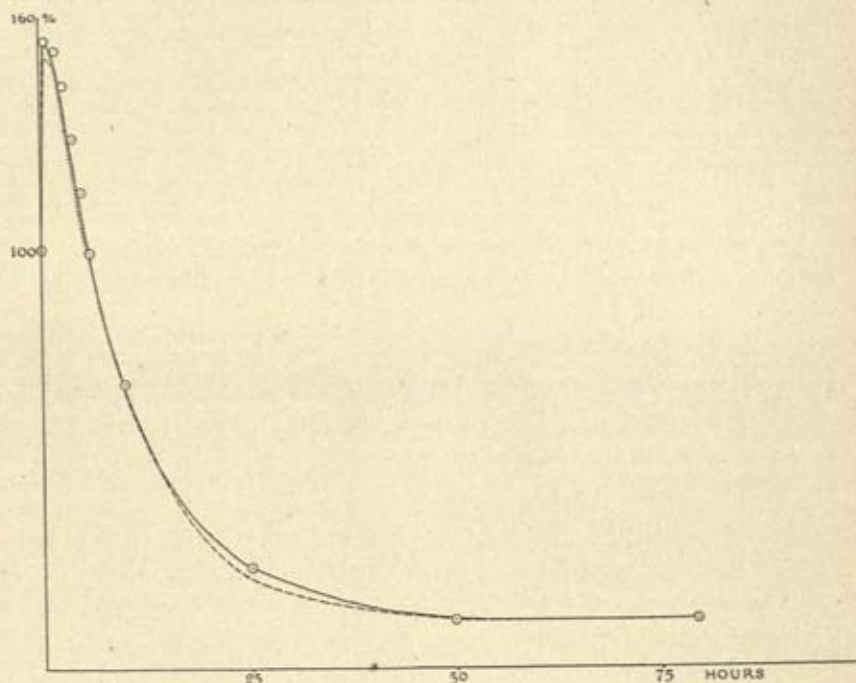


FIG. 11. Curve of electrical resistance of *Laminaria* in CaCl_2 (—), the trial curve (---) calculated from the velocity constants $K_1 = .0018$ and $K_2 = .0295$, and the theoretical curve (.....) calculated from the velocity constants $K_1 = .0017827$ and $K_2 = .0295$.

$\text{CaCl}_2 \text{ } 4.76$, K_2 would be large in pure NaCl , would diminish as CaCl_2 was added until it reached a minimum at $\text{NaCl } 95.24 + \text{CaCl}_2 \text{ } 4.76$ and would then rise steadily as more CaCl_2 was added.¹⁴

In this case it makes little difference whether the value of the

¹⁴ It might also be assumed that both K_1 and K_2 are increased by CaCl_2 (or both by NaCl) with a minimum effect at $\text{NaCl } 95.24 + \text{CaCl}_2 \text{ } 4.76$. But if only one salt controlled both K_1 and K_2 it would make little difference what the other salt was and this does not fit the facts.

constant is increased by the salt, the effect passing through a minimum, or diminished by the salt, the effect passing through a maximum.¹⁵

That catalyzers actually do act in this way is seen when acid catalyzes lipase, the effect of the acid passing through a maximum. It was found by Hoyer¹⁶ that when oxalic or sulphuric acid is added to lipase the action of the enzyme was accelerated in proportion to the amount of acid but that above a certain concentration the effect rapidly fell off.

Future investigations must decide which explanation fits the facts in the majority of cases.

We have thus reached a quantitative explanation of the results of our experiments. Our explanation indicates that the resistance is proportional to the amount of M which is present in the protoplasm. It may therefore be of interest to enquire how the substance M determines the resistance. If it is produced at the surface, as we assume, it may form a layer in the surface which offers resistance to the passage of ions. The amount of the resistance would then depend on the thickness (and continuity) of the layer. This may also apply to the internal surfaces, such as those of the nucleus, plastids, vacuoles, and microsomes.

It is evident that whether or not any of these assumptions be accepted certain facts seem to be established. It is clear that there are two processes, one of which produces a rise, the other a fall of resistance, and that their speed may be regulated by NaCl and CaCl_2 . It is extremely probable that these salts enter into chemical combination with some constituent of the protoplasm and it is evident that the compound thus formed might regulate the speed of one or both of these processes.¹⁷

¹⁵ In all these explanations it is understood that NaCl and CaCl_2 act in a saturated surface as explained above, so that only the relative proportions are important.

¹⁶ Hoyer, E., *Ber. deutsch. chem. Ges.*, 37(2): 1436, 1904.

¹⁷ It would seem that we can imitate completely the variations in resistance which occur in living protoplasm only when we have a system in which a reaction is going on which results in the production of a substance which is comparable to that designated as M in the foregoing discussion. Perhaps this explains why attempts to imitate these effects by experiments on colloids have not been more successful.

It is clear that such consecutive reactions as are here discussed must be the rule in living matter and that further study of their dynamics should yield facts of importance.

SUMMARY.

I. Data regarding the electrical resistance of living tissues of *Laminaria* in NaCl .52 *M*, in CaCl₂ .278 *M*, and in mixtures of these are given.

II. In order to explain these data it is assumed:

1. That the resistance is determined by a substance *M* which is formed and broken down by the reaction



2. That CaCl₂ accelerates the reaction $A \rightarrow M$.

3. That NaCl and CaCl₂ combine with a substance in the protoplasm, forming a compound which inhibits the reactions $A \rightarrow M$ and $M \rightarrow B$.

III. On the basis of these assumptions a theory is developed to explain:

1. Why both NaCl and CaCl₂ are toxic.
2. Why when mixed in the proper proportions their toxicity is greatly diminished (antagonistic action).
3. Why they have opposite effects on permeability.
4. Why the decrease of permeability produced by CaCl₂ must be followed by an increase when the exposure is sufficiently prolonged.
5. Why all toxicity disappears in sea water.

IV. The theory gives a quantitative explanation of the toxicity of all the mixtures and enables us to *predict the resistance (and permeability) in any mixture at any moment during exposure.*

V. The fact is emphasized that life processes must consist largely of consecutive reactions and that an analysis of the chemical dynamics of these reactions is indispensable for the solution of certain fundamental problems of biology.

HARVARD UNIVERSITY,

LABORATORY OF PLANT PHYSIOLOGY.

OBITUARY NOTICES
OF MEMBERS DECEASED.

SIR GASTON MASPERO.

(Read November 3, 1916.)

In the death of Sir Gaston Maspero on June 30, 1916, France has lost one of her most distinguished scholars—perhaps the most distinguished—and the world one of the leading Egyptologists, whose range of learning, however, extended far beyond the borders of Egyptological research.

Born in Paris in 1846 of parents who were of Italian descent, he received his early education at the Lycée Louis le Grand, famous for the long roll of great scholars that passed through its portals. From the Lycée he went to the Ecole Normale and while in that institution began to study Egyptian without the assistance of any master. At the age of nineteen he was able to translate Egyptian texts that had been submitted to him by Mariette Bey—at the time the leading Egyptologist of France. The feat, though remarkable for a young man, was not so astonishing as that at the age of twenty-three he was appointed to a professorship of Egyptology at the Ecole des Hautes Etudes—the graduate school of the Paris University. Four years later he had established his reputation for eminent scholarship so firmly as to be chosen to fill the chair of Egyptology at the Collège de France, created for the famous Champollion, who by the decipherment of the Rosetta Stone did for Egyptology in 1827 what a quarter of a century earlier the German scholar Grotefend had done for the Cuneiform inscriptions—establishing the decipherment on a secure basis. At twenty-seven he had thus attained to the highest scholarly post in the gift of the French government—the youngest person to have achieved the distinction. The story goes that a visitor came one day to see the already famous professor. The door of his apartment was opened by Maspero, who explained to his visitor that he was M. Maspero, whereupon the visitor insisted, "Oh, no; I want to see your father."

His first larger work appeared within two years after he had

been elected to the professorship to the Collège de France. It was a most ambitious undertaking—a "*Histoire Ancienne des Peuples de l'Orient*," covering Egypt, Babylonia, Assyria, Palestine and Syria—but it was carried out with the sure touch of a master. As a summary of what was then known of the Ancient East it acquired a high rank, as is indicated by the eight editions through which it passed, and by being translated into English and German. The work was an indication of the wide range of Maspero's studies even at that early age, and it was characteristic of the bent of his mind that while never losing sight of his special field of Egyptology, he correlated Egyptian history, religion and art with the history and achievements of the peoples with which Egypt had come into contact. In 1875, when Maspero's "*Ancient History*" appeared, it was still comparatively easy to master the entire field, because the historical and literary and archæological material recovered from the seats of the ancient empires of the East had not yet reached such large proportions, but with the steady course of excavations in Egypt, Mesopotamia and later in Palestine, Syria and Asia Minor, material of all kind increased rapidly. Scholars in all countries of Europe were attracted to the field, new journals to embody the results of detailed investigations were established, and as a result within each section of the field specialization led to further subdivisions. Under such circumstances it was well that there should be a few scholars with the courage, the learning and the ability to drive abreast through the whole field—men like Eduard Meyer in Germany, Sayce in England and Salomon Reinach in France. Maspero was a scholar of this broad type.

The new editions of his history, as called for, showed evidence of his keeping pace with new discoveries. Numerous investigations from him in the form of monographs and articles appeared in the technical journals and proceedings of learned societies of Europe and this country. The final upshot was the production at the time of the maturity of his intellectual powers of a monumental work in three large volumes appearing in French and English, which aimed to give a continuous narrative from the beginnings of civilization in the East to the close of the Persian Empire. The general title of this work—published in 1895-1897—was enlarged to "*Histoire An-*

cienne des Peuples de l'Orient Classique," with subdivisions in the English edition "The Dawn of Civilization," "The Struggle of the Nations" and "The Passing of the Empires." The framework of the smaller history was filled out down to the smallest details. As each of the ancient empires was taken up in turn, the oldest Egyptian and Babylonian principalities, the Egypt of the middle period, the Babylonian Empire at its height, Egypt in its glory, the Assyrian Empire, Hebrew history, the Philistines, the Phœnicians, and the nations of Syria and Asia Minor, notably the Hittites, the entire material is given to the reader in a most attractive and readable form, for like most of his countrymen Maspero knew not only how to investigate but how to write. His style, while not as brilliant as that of Renan and Taine, partook of the picturesque qualities of these unsurpassed masters, and was marked by epigrammatic aperçus and suggestive summaries as he reached the end of some particular episode, set forth with close attention to details. Nothing—not even the smallest article or even a note in an article in any of the journals of France, England, Germany, Holland, Italy or the United States—appeared to have escaped his keen eye. Only those who have themselves worked in any special field can appreciate what this meant, and what amazing and uninterrupted industry was involved in such a herculean labor. An inadequate index, which enhances the difficulty of consulting the work, is the one serious criticism to be passed on a product that still remains without a rival, even though in parts it has already become antiquated through the rapid increase of material—during the past twenty years—particularly for the older periods of Egyptian and Babylonian histories. It is also unfortunate, though not fatal to the work, that the translator has at times taken liberties with the original to make the results of critical study in connection with the history of the Hebrews more palatable to orthodox English readers.

The twenty years intervening between the appearance of Maspero's little history and his monumental work were the busiest in a career that knew no cessation of labor. In 1878 he himself established the first French journal to act as a medium for publishing the results of detailed studies bearing on Egyptology and Assyriology—the *Recueil de Travaux relatifs à la Philologie et à l'Archéologie*

égyptiennes et assyriennes, appearing quarterly. Maspero was not only the editor but the main contributor during the nigh forty years of its existence. Scarcely a number appeared without a contribution from his pen, and a contribution from Maspero invariably meant some addition to human knowledge, the result of an investigation of a new Egyptian text or of one as yet imperfectly understood, the determination of the meaning of an obscure Egyptian word or phrase, or the discussion of a grammatical problem. Many of the articles also dealt with archæological aspects or with the art, or entered into the domain of religious thought and theological speculation of the Egyptians on the basis of religious texts. In his articles in the *Recueil*, as in the many other journals—notably in England and Germany—to which he occasionally sent his contributions, he confined himself strictly to Egyptological studies; and through his efforts and example the somewhat loose method formerly prevailing in the interpretation of Egyptian texts, leading not infrequently to wild vagaries, gave way to accuracy and had its natural outcome in the creation of what is commonly known as the Berlin school of Egyptologists with scrupulous attention to grammatical details under the leadership of Adolf Erman—though it should at once be added that Egyptologists, being as human as physicians, do not always agree in their diagnosis of a grammatical form. Maspero often found himself in opposition to Erman, and Professor Breasted, of the University of Chicago, tells an amusing incident in this connection. Erman had written to Maspero to have the squeezes of the Pyramid inscriptions examined to ascertain whether certain verbal forms contained a letter *t* at the end. The point was of importance for settling a question of Egyptian grammar. Maspero entrusted several of his students with the task who reported that there were no traces of the *t*. “You see,” added Maspero, in recounting the incident to Professor Breasted, “the old Egyptians who wrote the Pyramid texts did not possess a copy of Erman’s grammar.” It subsequently turned out, however, that Erman was correct and that the *t* was there.

The anecdote affords an illustration of the difficulties that scholars in the earlier stages of the decipherment of strange signs, revealing a strange language, have to contend with. Decipherment of

a new script even when a key has been found necessarily involves "guessing"—and guesses may be right or wrong. It is only by rigid self-criticism and by testing results at every stage in the process of unravelling the mysteries of a script that the correct guess becomes a scientific fact. When Maspero began his career, the "guessing" stage had not yet been passed either in Egyptology or Assyriology; and though remarkable results had been achieved through scholars like Lepsius, Mariette, Brugsch and Le Page Renouf in Egyptian, and by Hincks, Rawlinson, Norris and Lenormant and Oppert in Assyriology, yet the ground was uncertain under the feet of men who still belonged to the age of the "pioneers." The main difficulty in the case of Egyptian was the absence of older texts. The Rosetta Stone belonged to a very late period, and until the active and systematic excavations began in Egypt in the late seventies, under Mariette, followed by the activities of the Egyptian Exploration Fund and of the German government, the texts at the disposal of scholars belonged for the larger part to the later dynasties of Egypt, what is now known as the Middle Kingdom. It was the great achievement of Maspero to have first made accessible the inscriptions found in the Pyramids at Sakkara—the cemetery of ancient Memphis—under which the kings of the fifth and sixth dynasties lay buried. The Pyramids were opened just at the time that Mariette, the distinguished and indefatigable head of the Bulak Museum, lay on his death-bed. News of the discovery was brought to him by his associate, Heinrich Brugsch, but it was left to Mariette's natural successor, the young Maspero, to copy the texts with his own hand and without delay to make them accessible. In the opinion of Egyptologists this achievement at the age of thirty-five remains his greatest work, for although some of his readings have been set aside and some of his interpretations have been superseded by later investigations, the decipherment was eminently successful. Through this feat he laid the foundations for the methodical study of Egyptian grammar on the basis of early and original texts, instead of later ones, which were in many cases imperfect copies. This applied more particularly to the great and miscellaneous collection of spells and hymns, conventionally known as the "Book of the Dead," the correct title of which is "The Book of the Going

Out into the Day." Maspero recognized that the Pyramid texts furnished in archaic form the oldest recension of the collection, and that these texts must primarily be used for determining the structure of the Egyptian language and for the study of the early religious beliefs. Maspero thus opened up the second era of Egyptological research, and associated his name for all times with that of Champollion.

He had been sent to Egypt in 1880 by the French government as the head of a mission to establish the Institut Français de l'Archéologie Orientale at Cairo—founded to carry on excavations and to promote archaeological research through publications. On the death of Mariette, the Khedive appointed Maspero as director of the Museum, a post which he retained for a period of five years. Despite his exacting labors in that capacity, rendered more difficult by the chicaneries of an Oriental government, he continued to edit his *Recueil* and to carry on his favorite researches. He also retained his professorship at the Collège de France and spent a portion of each year at Paris, devoted to teaching and writing. In 1883 he was elected a member of the Académie des Inscriptions et Belles-Lettres, and when in 1885 he resigned his post at Cairo, he returned to Paris the acknowledged head of French Egyptologists, recognized throughout the world as an authority of the very first rank.

The next fourteen years, from 1885 to 1899, were spent in Paris. During this period he devoted himself to the training of young students of Egyptology, and exhibited a fruitfulness in research even more astonishing than his previous achievements. Besides the articles in his *Recueil*, his contributions appeared in numerous journals outside his native land. Long memoirs alternated with shorter articles—ranging over the entire domain of Egyptology. Among popular works which appeared during this period were his "Life in Ancient Egypt," his "Manual of Egyptian Archaeology and Guide to the Study of Antiquities in Egypt" and his "Contes Populaires de l'Égypte Ancienne—the last named a collection of tales, charmingly translated into French with a delightful introduction, setting forth the nature of this branch of Egyptian literature. The collection includes the famous story of "The Two Brothers," which wandered to the ancient Hebrews and became part of the popular

folklore which found a literary expression in the dramatic story of Joseph and the wife of the Egyptian official who, by the way, was not Potiphar's wife. It is time to relieve this lady of the unjust suspicion that has attached to her for several thousand years.

In 1899 he was again called back to Egypt, this time as the director of the Service of Antiquities. By the Anglo-French agreement whereby, in return for allowing them free scope in Algiers, the French government waived further claims on Egypt in favor of the English, the English government granted the French the continuance of one privilege in Egypt—the supervision of the excavations of Egyptian remains. This concession was confirmed by the Convention of 1904 between England and France in regard to Morocco. The English were interested in live Egyptians and left the mummies to the French. I suppose that it is a fair question which nation got the better of the bargain. The living present is always troublesome—that is what it exists for—but it is a grievous error to suppose that the dead past belongs in the region where the wicked cease from troubling and the weary are at rest. If we allowed the dead past to bury its dead that might be the case, but archæology insists upon exhuming the past, and it is amazing to see how much trouble these old Pharaohs, who built their temples millenniums ago and who have been lying beneath their pyramids and in their rock-cut tombs for ever so long, can make when you dig them up. With English, French and German archæologists, backed by their governments, competing for the privilege of exhuming the past, the task of the mediator between rival claims was hard indeed. The reviving interest in archæological research made it imperative to have at the head of the Service, which was in control of all work on the tombs and temples, a man of tact and judgment, one in whose fairness and ability all could have confidence. One Frenchman after the other tried the job of director and left the post—exhausted by worry—and in an unhappy frame of mind. Maspero was called in as a last resort in 1899 and maintained the headship till 1914—a period of fifteen years.

If the preceding fourteen years were his years of greatest scientific activity, the succeeding fifteen were those of greatest public service. His time and strength were given to the difficult task be-

fore him, which involved the reorganization of the Service, in such a way as to ensure methodical explorations through the various agencies, the French Archæological Institute, the Egyptian Exploration Fund, the German Oriental Society, and the American institutions and certain individuals to whom permission to carry on the work was granted. The former loose methods were abandoned and the great monuments of ancient Egypt—such as the temples of Luxor and Karnak—were protected against spoliation.

A still greater task was his reorganization of the native museum, involving the transfer from inadequate quarters at Bulak to a splendid construction in Khasr-en-Nil at Cairo. Through the fruitful results of Egyptian excavations, the choice pieces of which remained in the country, this Museum has become the finest collection of Egyptian Antiquities in the world. At the same time such was the wealth of material recovered and such the wise, generous policy pursued by Maspero with his keen and unrivalled knowledge of Egyptian Archæology, knowing exactly what to keep and what to send out of the country to enrich the museums of Europe and the United States, the explorers received a suitable share of the discoveries made. To have carried out such a task successfully is to bestow the highest possible praise on the harmonious combination in one man of undisputed authoritative knowledge, keen judgment, wise tact, generosity, broadminded foresight and splendid executive abilities.

That during these years so fully occupied with executive duties he should have found it possible to keep himself abreast with the results of excavations carried on now by a large group of scholars in all parts of Europe and this country, and to have continued his own investigations in his contributions to the *Recueil*, to the publications of the French Archaeological Institute of Cairo and to numerous other journals, is a striking testimony to his marvellous powers of work. The preparation of a catalogue of the great Cairo collection, quite apart from the labor involved in its installation, would in itself have absorbed the energies of the ordinary scholar, who was not entirely swamped by the daily routine of executive duties. Maspero found time to bring out several volumes of "Etudes Egyptiennes" and to gather the memoirs and essays of French Egyptologists in a

"Bibliothèque Egyptienne," of which nine volumes alone constitute his own contributions, thus brought together from the various mediums through which they were originally published. He wrote a large number of less technical articles for the *Journal des Débats* and the literary periodicals of France, some of which were collected in a volume "Ruines et Paysages d'Egypte." He found time even to write reviews of the works of others. Most of these reviews were of publications within his special field, but not infrequently he went outside of it to call attention to productions in the larger realm of Oriental history, religion, archæology or art. It was a privilege indeed to have one's work passed upon by such a master. He could be severe and caustic, but he was also invariably kind and generous and encouraging to the younger men as they arose in the ranks. I trust that I may be pardoned for a personal allusion by referring to the encouragement that I received as a young man by the honor of having my first larger publication—about twenty years ago—reviewed by Maspero.

His last important work, published late in 1912 and appearing in several languages, was an illustrated manual "Art in Egypt" summarizing and elucidating the periods and characteristic features of Egyptian art in a manner that he alone, with his unrivalled knowledge, was capable of doing. This was followed in 1913 by an English translation of his collected "Studies in Egyptian Art" that had appeared in various journals during the past thirty years.

But he carried on all this heavy burden of activity at the expense of his health. His executive duties bore heavily on him as the years rolled on; the hours that he snatched for his own scientific and literary labors were stolen from a leisure to which he was richly entitled. For him, as for so many unceasing workers, the motto of life was "Repos ailleurs"—a noble but a fatal motto. I saw Professor Maspero for the last time in the spring of 1912. During the fifteen years that had elapsed since I met him in Paris at the International Congress of Orientalists, he had grown old and he appeared to be—what in effect he was—worn out by his incessant labors. He apologized for not being able to devote more time to visitors, because of the pressure of the work, and one saw that he was obliged to be feverishly active in order to get through the tasks

of the day. He complained in his quiet way that he was obliged to spend his days in executive and routine tasks. "Only the evenings," he remarked, "can I call my own, and these I must reserve for my work."

His health began to fail, as a result, no doubt, of this strain; his eye-sight, too—he was always very near-sighted—began to suffer, and in the spring of 1914 he resigned his post in the hope of enjoying some remaining years to be devoted to his favorite studies, and in carrying on the congenial duties of *Secrétaire Perpétuel* of the *Académie des Inscriptions et Belles-Lettres*, to which he was elected when it became known that he intended to return to Paris. He reached home in August, just as the War broke out, only to be struck down by an attack of heart disease, from which he never fully recovered. The War brought deep sorrow to him as a French patriot, and also a severe personal bereavement in the death of his talented son, Jean Maspero, who fell in battle on the 17th of February, 1915. Jean Maspero was following in the footsteps of his father and had already achieved a high reputation as one of the most brilliant of the younger scholars of France when he gave up his life to his country. The father writes pathetically of this: "Until now I felt considerably younger than my age. I cannot tell you how I have aged in a few months." The blow, no doubt, hastened the end, and he died suddenly at a meeting of the French Academy, of which for over forty years he had been one of the most distinguished members.

The death of Maspero suggests a remark of a more general character. To the man of science such a catastrophe as this, the most tragic war in history, brings a sorrow additional to that which affects the patriots of all the belligerent nations (and of neutrals as well), for it means the severance of international ties which in the case of Maspero were particularly numerous and close. Through his writings and through his directorship of the *Service of Antiquities* he was brought into contact with the scholars of all nations—not least with the savants of Germany, whose activity in Egyptology, as in all branches of science, is so marked. His *Recueil* was open to the scholars of all lands—its international character was shown by the large number of contributions that appeared in it in German and English. Absorbed as we naturally are by the more ob-

vious tragic aspects of the great conflict, by the frightful loss of life and by its economic disasters, we seldom stop to think of its appalling effect in severing the international bonds created by scholarship, and which count for so much in the advancement of human knowledge. Scholarship is perhaps the most potent of the forces working for amity and mutual understanding among nations, upon which in the last analysis the peace of the world rests. International gatherings of scholars, that have multiplied greatly during the past twenty years and now cover all fields—medicine, the natural sciences, philosophy, psychology, anthropology, philology, history and archæology, were contributing towards this end. At one blow all these efforts were swept aside and all hopes for the future shattered. Maspero must have felt—perhaps more keenly than most scholars—the cruel stroke which undid the work of years. Without the coöperation of the scholars of all countries—and more particularly of the two, France and Germany, that take the lead in scholarship in most fields—international congresses are impossible. This generation will pass away before a new era may dawn when the scholars of the world will again be enabled to meet in council and to work together for the advancement of the highest aims of humanity.

Many were the honors that came to Maspero during his career from all parts of the world. The Academies of England, Germany, Austria, Holland, Belgium and Italy and the learned societies of this country elected him to honorary membership. The American Philosophical Society elected him to membership in 1891. In 1909 King Edward bestowed a knighthood on him in recognition of his eminent services to science—a very exceptional distinction in the case of a foreigner. He was made a Knight-Commander of St. Michael and St. George; but perhaps the most significant of all tributes to him is the circumstance that the directorship of the Service still remains vacant, two years after he left it. This may be due in part to the war, but in large part it is because no one has been found fitted to take his place.

If there is such a thing as a fitting death, Sir Gaston Maspero was granted this privilege—to pass away under the shadow of the venerable edifice on the Seine that symbolizes the intellectual glory of France, and to whose luster he added by his distinguished career.

MORRIS JASTROW, JR.

SAMUEL DICKSON.

(Read December 1, 1916.)

I have been asked to present a paper commemorative of our late associate, Samuel Dickson. It is hard to realize that he is dead. We have seen him in this hall so often that his present appearance in yonder doorway would not seem unnatural. Whenever he entered our assembly all eyes turned towards him instinctively. His tall form, his almost majestic mien, his white hair, his shaggy eyebrows, his carefully trimmed beard and his air of distinction compelled attention. I recall that when Nansen, the Arctic explorer, was addressing us, it so happened that Mr. Dickson, Senator George F. Edmunds and Admiral Melville sat side by side in the front row, and as I looked at these leonine men I realized what the Gauls must have felt when first they saw the Roman Senate.

Mr. Dickson was a marked man intellectually. Whatever he said, whatever he wrote attracted attention. Judge McPherson has put it in the happiest way:

"And who wrote better English? Everything to which he set his pen had a certain distinction about it, a crisp and vivid handling, a happy turn of phrase, the choice of the inevitable word. He possessed that indefinable something we call the literary touch, the atmosphere of refinement, of abounding knowledge, of quiet power, of balanced judgment, of unfailing good taste, that can never be acquired as one acquires a mechanic art. . . . It was a keen pleasure to hear him talk even in the casual ease of familiar speech; it was a delight to read anything he took the trouble to write, for he wrote nothing carelessly, but was at pains to leave his admirable stamp upon correspondence and minute and formal address alike. We have all enjoyed and profited by his too rare letters upon public questions, and were always sure that the familiar (S. D.) at the end was a guaranty of thoughtful, lucid discussion, always adorned by the grace of expression, and often illumined by the lambent play of irony or humor."

Mr. Patterson of the Pittsburgh bar, who has succeeded Mr. Dickson as chairman of our State Board of Law Examiners, said of him:

"As you came in contact with him you felt that atmosphere—I hardly know how to describe it. It was more like the fabled breeze that did not come from the haunts of men. Tennyson, you remember, described the wind that blows all day in a land 'where no man is or hath been since the making of the world.' That expresses my thought somewhat of something which is entirely apart or free from any stain or taint of other things or of personality. Farther even would he go than those of us who were with him could go, and never once did he falter in the integrity, clearness and the forcibleness of his conclusions."

Hon. John Bassett Moore said of him:

"Always abreast of the times, eagerly noting the latest developments in science, in industry and in politics, it may be said that he made almost daily excursions into the fields of history and literature. He did not, indeed, figure in the category of omnivorous readers, who devour voraciously whatever falls in their way, good and bad. His mind was too delicately and sensitively organized for such a feat. He was singularly discriminating. The worthless he instinctively rejected, but there was little of real and permanent value that escaped him. As a result it was always a delight to talk with him, and his interlocutor never went away emptyhanded. On the contrary, although he might feel a sense of hunger rather than of satiety, he could at any rate affirm in the felicitous phrase of Dryden, that he had 'not wanted sweet discourse, the banquet of the mind.'"

Mr. J. Levering Jones, one of Mr. Dickson's colleagues in the board of trustees of the University of Pennsylvania, said of him:

"There was a delicate austerity in his sense of honor. Deviation from intellectual or legal rectitude was intolerable to him. Upon a question where either was involved, he made no argument. He would simply make a gesture and render a decision. . . . He possessed a native dignity of manner, but mingled with it an unaffected modesty. This gave him the fortunate faculty, in the discussion of moral questions, of separating himself from the subject under consideration. What he said, therefore, became charged with an unusual and invincible force. He rested, in such observations, upon simple and eternal principles. He conveyed no idea of personal relation to them. As a declarant or analyst he was only dealing with ethical and spiritual matters."

Mr. C. Stuart Patterson said of him:

"He was a man of strong convictions, and he never was lacking in the courage needed for their expression, and yet he was exceptionally broad-minded and tolerant of differences of opinion, and he could always see and do full justice to the merits of the opposing view. He was by temperament conservative; yet, even in his later years, his conservatism was not the unreasoning conservatism of old age, but it was an intelligent conservatism based upon an accurate knowledge of existing conditions, and a just estimate of the probable results of proposed innovations. In social intercourse Mr. Dickson

was one of the most delightful of companions. His reading had been wide and varied, and he had thought much as to that which he had read. His talk was

“‘Rich with all treasure updrawn from the crypt
Where lies the learning of the ancient world.’”

Former Chief Justice Mitchell said:

“Mr. Dickson was naturally a scholar, a student. In his younger years he might even have been called a bookish man. In that way he laid a foundation of theoretical knowledge, which fortunately for him and for us, quite early in life was supplanted by an equipment which is derived nowadays from what might be called business colleges. He developed a practical quality that never was surpassed by any of his contemporaries. Yet, with all the years devoted to the most important litigation, he never quite forgot his natural bent of scholarship. . . . Naturally a student, he became as active and as accomplished a man of affairs as the Philadelphia Bar possessed.”

Chief Justice Brown said:

“A prince in our Israel has fallen. Full of years and full of honors he has gone to his fathers in peace. His hoary head was a crown of glory, for his ways were ways of righteousness. . . . Samuel Dickson was a good man, whose memory is precious to all who knew him. He was singularly faithful to every duty that came to him; he was cultured and refined; he was an upright citizen, a very learned lawyer and a Christian gentleman.”

I have culled these tributes and these discriminating and penetrating analyses of his character from the Proceedings of the Meeting of The Philadelphia Bar, held June 7, 1915, and placed them side by side because they give you a complete picture of the man. It only remains for me to give you a sketch of his active life.

He was born at Newburgh, New York, February 2, 1837, and came when a lad to the city of Philadelphia, comparatively unknown, and with no advantage of local relationships. His school days were spent in the Classical Institute of the Rev. John W. Faires, the best teacher of his time in preparing boys for college. He entered the Arts Department of the University of Pennsylvania in 1851, and graduated in 1855 with the degree of B.A. Registering as a student of law in the office of Constant Guillou, Esq., he was admitted to the bar in October, 1858, supporting himself during this term of three years by acting as first assistant in the school of Dr. Faires, instructing the highest classes in Greek and Latin, and to the end of his days his Homer and his Horace were as familiar to his

pen and tongue as Shakespeare, Wordsworth, Byron and Keats. While waiting for practice he devoted himself for two years to editorial labors upon *The Age*, the then leading Democratic newspaper published in Philadelphia. The skill and the experience he there acquired gave him "the pen of a ready writer," an accomplishment he never lost. In December, 1860, he became the librarian of the Law Association of Philadelphia as the successor of the scholarly bibliophile, John William Wallace, who later became the reporter of the decisions of the Supreme Court of the United States and still later president of the Historical Society of Pennsylvania. From the old folios and black letter octavos illustrating the growth of the English Common Law, collected largely by Mr. Wallace, Mr. Dickson acquired that knowledge of legal bibliography and that taste for legal history which in after years contributed so largely to the matter and manner of his forensic discussions.

From the fate of the bookworm and the meager salary of a librarian he was snatched in 1865 by the discernment of that incomparable business man's businesslike lawyer John C. Bullitt, who appreciated the learning and legal ability of younger men, and had need of a partner so equipped. Thus Mr. Dickson was, quite early in life, introduced to business associations, which later he came to command. The law partnership thus formed in 1865 lasted until Mr. Bullitt's death in 1902. A third partner was admitted in the interim in the person of Richard C. Dale, whose untimely death in 1905 deprived the profession of one of its most conspicuous ornaments and buttresses of strength. He then organized the present firm of Dickson, Beitler and McCouch. He served as a member of the committee of censors of the Law Association of Philadelphia from 1873 to 1890 and was a stern upholder of the purity of legal ethics. He served again in this position from 1872 to 1896, when he became the vice-chancellor of the Association, serving for three years, when he was elected chancellor and held the place by successive annual re-elections for ten years, a term of service exceeded only by Mr. Wm. M. Meredith and Mr. George W. Biddle out of a list of ten predecessors, and which, under the present by-laws, can never again be equaled. He served his alma mater as a trustee of the University of Pennsylvania for a period of thirty-three years—from 1881 until

his death—having been a member of the Law Committee since 1882, chairman of that committee since 1896, and a member of the Finance Committee since 1894.

In 1895 he acted as chairman of a committee of twenty-one leaders of the bar from all parts of the commonwealth which organized the Pennsylvania Bar Association, and was chosen its second president. His address as president, upon "The Development in Pennsylvania of Constitutional Restraints upon the Power and Procedure of the Legislature," was as notable as a historical treatise upon our constitutional growth as it was admirable for the clearness and vigor of its views. After yielding his presidency he did not, as so many ex-presidents did, lose interest in the work, but continued his active relationship to the Association, and in 1902, largely at his instance, and because of his character, which was a sufficient surety against unfair or arbitrary discrimination in the exercise of new and unusual powers, the Supreme Court created the State Board of Law Examiners of five members, and appointed him a member. He immediately became its chairman and remained in that position until his death. His successor as chairman has described him exactly: "Though thus the central figure of that organization and the representative of the Bar of the state, he impressed one strongly with the fact of his complete ignorance of his being the one or the other. He moved among us as quietly and as gently, as inconspicuously, as a tyro. It was an achievement. It was something out of the way to see one who was so great pass so quietly and modestly among us."

In June, 1907, he was appointed by the board of judges a member of the board of directors of the City Trusts of Philadelphia charged specifically with the practical administration of the estate of Stephen Girard, and served that most splendid of municipal charities with active and well-informed zeal until the close of his life. He was a manager of the Wistar Institute of Anatomy and Biology, founded by the munificence of our own former president Isaac Wistar. He sat as director in the boards of fifteen corporations, among which were the Lehigh Coal and Navigation Company, The Lehigh and New England Railroad Company, The Lehigh and Wilkes-Barre Coal Company, The Lehigh Navigation Electric

Company, The Fourth Street National Bank, and The Corn Exchange National Bank. The mere mention of these names is sufficient to attest the magnitude and importance of their interests. He was also a member of no less than thirty literary, social, scientific and charitable associations, of which The Shakespeare Society, The Mahogany Tree Dining Club, The Lawyers' Club, The Legal Club, The American Bar Association, The Down Town Club, and The Triplets are deserving of particular mention. During the life time of Judge Sharswood, he was a member of a small but choice coterie especially interested in the study of political economy, among whom were the late E. Coppeé Mitchell and James Parsons, both of whom were subsequently in the faculty of the Law School; and he was also interested in the literary studies of the English poets of the Lake School conducted by the late Asa I. Fish, a man of "fragrant memory," to use an old but expressive phrase.

His relations to the American Philosophical Society date from his election as a member April 18, 1884. He served as councillor during the years 1906-08, 1910-12, and 1914-15. He also, from time to time, served on important committees, notably the one charged with the arrangements of the Franklin Bi-Centennial. He was elected to the Wistar party in 1887 and was chairman of its executive committee from 1902-1909, in which latter year he succeeded Henry Charles Lea as Dean, and served in that office until his death. As a host he was charming, radiating hospitality and warmth.

Mr. Dickson was a widely travelled man both in Europe and America. One who knew him well wrote:

"He had a wonderful remembrance of the places visited and could lay out from memory an itinerary for a friend in Italy or Switzerland which was practicable in every detail. His travels in Greece were the subject of a delightful address delivered at the University of Pennsylvania. Music he loved, and the theater and his recollections of the great singers and actors made an interesting part of his many-sided conversation."

I myself recall a scene of my law student days, when on visiting the Catskills I saw Mr. Dickson, then in his very prime, seated upon the broad ledge of rock, which jutted out over the valley in front of the Mountain House, in animated conversation with Mr. Justice

Bradley of the Supreme Court of the United States; the venerable Chief Justice Beasley of New Jersey, George Harding, the famous patent lawyer who had won the Morse Electric Telegraph case, and the McCormick Reaper case, and the quaint old-fashioned Asa I. Fish, who was physically the counterpart of Mr. Pickwick, and mentally his exact opposite. It was an unusual company for a law student to join, and I listened to a discussion of the famous Slaughter House Cases, but recently decided by the highest tribunal in the nation, where Justices Bradley and Field had dissented from the majority, a discussion which impressed me deeply, so animated had the debate become. Many years later I saw Mr. Dickson on the broad piazzas of the United States Hotel at Saratoga in conversation with E. J. Phelps, of Vermont, and Joseph H. Choate, both of them subsequently ambassadors to Great Britain, and grouped about them were Morefield Storey, of Boston, Simeon E. Baldwin, of Connecticut, judge, governor and publicist, and John F. Dillon, who left the federal bench to become a renowned advocate before the Supreme Court of the United States; James C. Carter, the greatest forensic jurist of his day, and Henry C. Hitchcock, of Missouri, an eminent disciple of the school of John Marshall. It is no wonder then that with such associates Mr. Dickson became "one of the honor men of the Bar of the United States." Indeed, it is known that when, through the death of Chief Justice Waite, a vacancy existed in the highest judicial office of the nation, President Cleveland seriously contemplated sending Mr. Dickson's name to the Senate, and nothing but a narrow view of his relationship as counsel to great corporations prevented his doing so.

It is as a leader of the Bar that he must be finally considered. Admitted to the Bar of Philadelphia in 1858, of all the men who were slightly his seniors in standing but seven survived him, and of the fifty-nine men who were admitted in the same year but two remained. This impressive fact, while in one sense indicating the average shortness and uncertainty of life, in another illustrated the persistency of his leadership. From 1776 to 1858—a period of eighty-two years—there were admitted to the Philadelphia Bar in all 2,786 men: at the time of his death there were 2,936 names upon the roll of living lawyers. This*fact indicated the great growth in

Bar membership during the life time of Mr. Dickson, and emphasized not only the relative significance of his leadership, but the circumstance that to the vast majority of the present Bar he must have appeared as a venerable man. In truth, it is the prolonged life of a great leader that binds the generations and centuries of lawyers together. Just as Horace Binney bound his own generation of Sergeants and Chaunceys to that of William Lewis, Edward Tilghman and Jared Ingersoll—the leaders of the Old Bar, as Mr. Binney called them in his classic brochure of that title—and just as Mr. Wm. M. Meredith bound that of John M. Read, George Stroud, Eli K. Price and John Cadwalader to that of Mr. Binney, so Samuel Dickson has bound his own generation to that of George Sharswood, William Strong, R. C. McMurtrie, George W. Biddle, Furman Shepard and Theodore Cuyler. It is curious to note how long some of these overlapping lives have been, for while more than half a generation younger than Mr. Dickson, I can distinctly recall not only the forms and the features, but even the voices of Horace Binney, who was admitted to the Bar in 1800; of James J. Barclay and Henry J. Williams, who were admitted in 1815; of David Paul Brown, who was admitted in 1816; of William M. Meredith, who was admitted in 1817; and of Eli K. Price, who was admitted in 1822. Yet each man stood in his day and generation for certain distinct phases of legal principles which cannot be confounded with those of a later time.

The law, while fixed and stable, undergoes successive changes, due to the development of society and to the multiplication of business issues which vary from generation to generation. Mr. Dickson's career is a striking illustration of this. While Mr. McMurtrie and his contemporaries relied upon the law of Lord Tenterden, Chief Justice Gibson and Baron Parke, and upon the equity of Lord Eldon and Chief Justice Tilghman, Mr. Dickson, while thoroughly familiar with the older precedents, espoused and enforced in argument the law of Baron Bramwell, Lord Blackburn and Mr. Benjamin and the equity of Sir George Jessel, Lord Esher and Lord Cairns. His arguments in the Supreme Court of the United States are proofs of this, notably in *Norrington vs. Wright* (115 U. S. 188), and *Meehan vs. Valentine* (145 U. S. 611), in the first of

which he discussed the divisibility of a time contract to be met by instalment deliveries, and in the second, in which he sustained the more recent rule that participation in profits is presumptive but not conclusive proof of a partnership. In the same way his numerous engagements in the Federal Courts, and in the Supreme Court of Pennsylvania, illustrate the extent and the character of his devotion to the complex and varied questions arising out of railroad receiverships, coal carrying and mining contracts, and the various efforts at legislative restrictions upon vast combinations of capital, both corporate and individual.

In the law of receiverships he was both a creator and an expert, and his arguments here acquired a permanent value as illuminating a once darkened chamber of equity jurisprudence. His forensic work in the lower courts, both in the Common Pleas and the Orphans Court, were marked by the same excellence, thoroughness of preparation and clearness of presentation. While making no claim to eloquence or skill in cross examination, yet in assisting his colleagues in sifting and arranging evidence and in the preparation of briefs, he never overlooked a point or neglected a pertinent authority. Mr. Bullitt leaned heavily upon him in the Whitaker will case, a case as renowned in our annals as the famous Tichborne claim in England. And after Mr. Bullitt had gone and Mr. Dickson took the lead, his arguments were models of simplicity and strength, for he never imagined himself profound in proportion to the ability to make one's self obscure. Clearly do I see the shade of Samuel Dickson joining that majestic procession of venerable men ascending the empurpled heights which Virgil tells us belong to the immortals.

BIBLIOGRAPHY.

His address, entitled "Ten Days in Greece"; "The Methods of Legal Education;" "Powers and Procedure of the Legislature;" "George Sharswood;" "The Dedication of the New Law School Building;" the "Introductory Address," delivered by him as chancellor of the Law Association, upon the celebration of its Centennial in March, 1902, and his argument before the Anthracite Strike Commission, have been published and disclose a lasting basis for his fame.

HAMPTON L. CARSON.

MINUTES

MINUTES.

Stated Meeting January 7, 1916.

ARTHUR W. GOODSPEED, Ph.D., in the Chair.

Rev. James W. Robins, D.D., owing to his inability to attend the meetings of the Society, presented his resignation of membership.

The decease was announced of

Richard Stockton Hunter, at Philadelphia, on December 17, 1915.

Rt. Hon. Sir Henry Enfield Roscoe, at Leatherhead, Surrey, England, on December 18, 1915, æt. 82.

Arthur W. Wright, Ph.D., at New Haven, on December 19, 1915, æt. 80.

George Albert Lewis, at Philadelphia, on December 23, 1915, æt. 86.

The following papers were read:

"The Determination of Distances of Stars from Us," by Prof. John A. Miller.

"The Geology of Sergipe and Northeastern Bahai," by Ralph H. Soper. (Communicated by Prof. John C. Branner.)

The Judges of the Annual Election held on this day between the hours of 2 and 5 in the afternoon, reported that the following named members were elected according to the rules, regulations, and ordinances of the Society, to be the Officers for the ensuing year:

President.

William W. Keen.

Vice-Presidents.

William B. Scott,
Albert A. Michelson,
Edward C. Pickering.

MINUTES.

Secretaries.

I. Minis Hays,
Arthur W. Goodspeed,
Amos P. Brown,
Harry F. Keller.

Curators.

Charles L. Doolittle,
William P. Wilson,
Leslie W. Miller.

Treasurer.

Henry La Barre Jayne,

Councillors.

(To serve for three years.)

Louis A. Bauer,
Edward P. Cheyney,
Russell H. Chittenden,
Charles D. Walcott.

Stated Meeting February 4, 1916.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

Prof. William E. Lingelbach (introduced by Prof. Emory R. Johnson) read a paper on "Nationalism and the European War."

Stated Meeting March 3, 1916.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

The decease was announced of Sir William Turner, K.C.B., F.R.S., at Edinburgh, on February 15, 1916, æt. 85.

The following papers were read:

"Predominating Reactions among the Hydrocarbons," by Walter F. Rittman, Ph.D. (Introduced by Dr. Keen.)

"The Pathological Anatomy of Injected Chestnut Tree," by Caroline Rumbold, Ph.D. (Introduced by Prof. Macfarlane.)

Stated Meeting April 7, 1916.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

The following invitations were received:

From the New Jersey Historical Society to be represented at the opening ceremonies of the 250th anniversary of the founding of Newark, to be held on May 1, 1916.

From the Massachusetts Institute of Technology to be represented by a delegate at the opening of its new buildings on June 14, 1916.

The decease was announced of the following members:

H. C. Humphrey, on January 9, 1916.

Louis Duncan, Ph.D., U. S. N., on February 13, 1916, æt. 53.

William Angus Knight, LL.D., on March , 1916, æt. 81.

James Burrill Angell, LL.D., at Ann Arbor, on April 1, 1916, æt. 87.

The following papers were read:

"The Moving Coil Galvanometer and the Recent Improvements in its Construction and Use for Direct Deflection Work of Precision," by Anthony Zeleny, Ph.D., of Minneapolis.

"On Ethnological Tests of Sensation and Perception," by E. B. Titchener, D.Sc., LL.D., of Ithaca.

*Stated General Meeting April 13, 14, and 15, 1916.**Thursday, April 13.*

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

Hermion Carey Bumpus, Ph.D., Walter Bradford Cannon, A.M., M.D., John Merle Coulter, Ph.D., Luther Pfahler Eisenhart, Ph.D., Leland Ossian Howard, Ph.D., Raymond Pearl, Ph.D., and John Zeleny, Ph.D., recently elected members, subscribed the Laws and were admitted into the Society.

The decease was announced of Harry Clary Jones, Ph.D., at Baltimore, on April 9, 1916, æt. 50.

The following papers were read:

"The Popes and the Crusades," by Dana C. Munro, A.M.,

- L.H.D., Professor of Medieval History, Princeton University.
- "The Common Folk of Shakespeare," by Felix E. Schelling, Ph.D., Litt.D., Professor of English Literature, University of Pennsylvania.
- "A Rare Old-Slavonic Missal," by J. Dyneley Prince, Ph.D., Professor of Semitic Languages, Columbia University.
- "On the Art of Entering Another's Body: A Theme of Hindu Fiction," by Maurice Bloomfield, Ph.D., LL.D., Professor of Sanskrit, Johns Hopkins University.
- "The Interpretation of Mythology," by Franz Boas, Ph.D., Sc.D., LL.D., Professor of Anthropology, Columbia University.
- "America's Relation to the Developments of International Law," by Leo S. Rowe, Ph.D., LL.D., Professor of Political Science, University of Pennsylvania.
- "The Work of the Mellon Institute in its Relations to the Industries and to the Universities," by Raymond F. Bacon, B.S., A.M., Ph.D., Director, Mellon Institute of Industrial Research, University of Pittsburgh. (Introduced by Dr. Keen.)
- "Sight and Signalling in the Navy," by Alexander Duane, M.D., of New York. (Introduced by Dr. de Schweinitz.)
- "Observations of the Mentality of Chimpanzees and Orangutans" (illustrated with motion pictures), by William H. Furness, 3d, A.B., M.D., of Wallingford, Pennsylvania.

Friday, April 14.

Executive Session—9.30 o'clock.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

The Proceedings of the Officers and Council were submitted and the following nominees for membership were recommended for election this year:

Residents of the United States.

William Wallace Atterbury, A.M., Radnor, Pa.

Maxime Bôcher, A.B., Ph.D., Cambridge, Mass.

Percy Williams Bridgman, Ph.D., Cambridge, Mass.
James Mason Crafts, S.B., LL.D., Boston, Mass.
Henry Platt Cushing, Cleveland, Ohio.
Edward Murray East, M.S., Ph.D., Boston, Mass.
Frank Rattray Lillie, Ph.D., Chicago, Ill.
William E. Lingelbach, A.B., Ph.D., Philadelphia.
Daniel Trembly MacDougal, A.M., Ph.D., Tucson, Ariz.
Charles Frederick Marvin, M.E., Washington, D. C.
Lafayette Benedict Mendel, A.B., Ph.D., Sc.D., New Haven,
Conn.
Forest Ray Moulton, Ph.D., Chicago, Ill.
Eli Kirk Price, A.B., LL.B., Philadelphia.
Erwin Frink Smith, Sc.D., Washington, D. C.
William Morton Wheeler, Ph.D., Boston, Mass.

Foreign Residents.

Frank Dawson Adams, D.Sc., Ph.D., F.R.S., Montreal.
Wilhelm L. Johannsen, M.D., Ph.D., Copenhagen.
Joannes Diderik van der Waals, Ph.D., Amsterdam.

Morning Session—9.35 o'clock.

WILLIAM B. SCOTT, Sc.D., LL.D., Vice-President, in the Chair.

The following papers were read:

"Two New Terms, Cormophytaster and Xeniophyte, axiomatically fundamental in Botany," by William Trelease, Sc.D., LL.D., Professor of Botany, University of Illinois, Urbana.

"Origin and Vegetation of Salt Marsh Pools," by John W. Harshberger, Ph.D., Professor of Botany, University of Pennsylvania.

"The F_2 Generations, and Back-, and Inter-crosses of the F_1 Hybrids between *Ænothera nutans* and *pyncocarpa*," by George F. Atkinson, Ph.D., Head of Department of Botany, Cornell University.

"Inheritance through Spores," by John M. Coulter, A.M., Ph.D., Professor of Botany, University of Chicago.

- "The Dynamics of Antagonism," by W. J. V. Osterhout, A.M., Ph.D., Professor of Botany, Harvard Univ. (Introduced by Prof. Davis.)
- "Jointing as a Fundamental Factor in the Degradation of the Lithosphere," by Frederick Ehrenfeld, Ph.D., Assistant Professor of Geology, University of Pennsylvania. (Introduced by Prof. Amos P. Brown.)
- "Sinking Islands versus a Rising Ocean in the Coral-Reef Problem," by William Morris Davis, Sc.D., Ph.D., Professor Emeritus of Geology, Harvard University.
- "The Petrology of Some South Sea Islands and its Significance," by Joseph P. Iddings, Sc.D., late Professor of Petrology, University of Chicago.
- "Coal Formation," by J. J. Stevenson, Ph.D., LL.D., Emeritus Professor of Geology, New York University.
- "California Lakes and the Solar Hypothesis of Climatic Changes," by Ellsworth Huntington, M.A., Ph.D., Assistant Professor of Geography, Yale University. (Introduced by Mr. Henry G. Bryant.)
- "Color Photographs of the Phosphorescence of Certain Sulphides," by Edward L. Nichols, Ph.D., LL.D., Professor of Physics, Cornell University.

Afternoon Session—2 o'clock.

WILLIAM B. SCOTT, Sc.D., LL.D., Vice-President, in the Chair.
The following papers were read:

- "A New and Very Sensitive Indicator for Acidimetry and Alkalimetry and for Determining Hydrogen Ion Concentrations between the Limits of 6 and 8 on the Sorensen Scale," by G. Scatchard and Marston T. Bogert, Ph.B., LL.D., Professor of Organic Chemistry, Columbia University.
- "Bacterio-chemical Studies of Decay of the Teeth," by William J. Gies, Ph.D., Professor of Biological Chemistry, Columbia University.
- "The Human Gastric Secretion," by Martin E. Rehfuess, M.D., Research Associate in Physiological Chemistry, Jefferson

Medical College, Philadelphia. (Introduced by Dr. Philip B. Hawk.)

"Cerebral Localization," by Harvey Cushing, A.M., M.D., Professor of Surgery, Harvard University. (Introduced by Dr. Keen.)

"The Inorganic Constituents of Marine Invertebrates," by Frank Wigglesworth Clarke, D.Sc., LL.D., Chief Chemist, U. S. Geological Survey.

"Some Properties of Vibrating Telephone Diaphragms," by A. E. Kennelly, S.D., A.M., Professor of Electrical Engineering, Harvard University, and H. O. Taylor, of Cambridge.

"(A) Dimensional Gases and the Law of Reflection of Gas Molecules from Solid Walls; (B) The Metallic Reflection of Light from a Gas," by Robert Williams Wood, A.B., LL.D., Professor of Experimental Physics, Johns Hopkins University.

"Some Relations between Matter and Radiation," by William Duane, A.M., Ph.D., Assistant Professor of Physics and Research Fellow of the Cancer Commission, Harvard University. (Introduced by Prof. A. W. Goodspeed.)

"Relation between Changes in Solar Activity and the Earth's Magnetic Activity, 1902-1914," by Louis A. Bauer, Ph.D., Sc.D., Director of the Department of Terrestrial Magnetism of the Carnegie Institution, Washington, D. C.

Evening Session—8 o'clock.

Leland Ossian Howard, Ph.D., M.D., LL.D., Chief of the Bureau of Entomology, U. S. Dept. of Agriculture, gave an illustrated lecture "On Some Disease-Bearing Insects."

Saturday, April 15.

Executive Session—9.30 o'clock.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.
The pending nominations for membership were read.

Secretaries Brown and Keller acted as tellers of the election, and the Society proceeded to ballot for members.

The Secretaries subsequently reported that the following nominees had been elected to membership:

Residents of the United States.

William Wallace Atterbury, A.M., Radnor, Pa.
Maxime Bôcher, A.B., Ph.D., Cambridge, Mass.
Percy Williams Bridgman, Ph.D., Cambridge, Mass.
James Mason Crafts, S.B., LL.D., Boston, Mass.
Henry Platt Cushing, Cleveland, Ohio.
Edward Murray East, M.S., Ph.D., Boston, Mass.
Frank Rattray Lillie, Ph.D., Chicago, Ill.
William E. Lingelbach, A.B., Ph.D., Philadelphia.
Daniel Trembly MacDougal, A.M., Ph.D., Tucson, Ariz.
Charles Frederick Marvin, M.E., Washington, D. C.
Lafayette Benedict Mendel, A.B., Ph.D., Sc.D., New Haven, Conn.
Forest Ray Moulton, Ph.D., Chicago, Ill.
Eli Kirk Price, A.B., LL.B., Philadelphia.
Erwin Frink Smith, Sc.D., Washington, D. C.
William Morton Wheeler, Ph.D., Boston, Mass.

Foreign Residents.

Frank Dawson Adams, D.Sc., Ph.D., F.R.S., Montreal.
Wilhelm L. Johannsen, M.D., Ph.D., Copenhagen.
Joannes Diderik van der Waals, Ph.D., Amsterdam.

Morning Session—10 o'clock.

EDWARD C. PICKERING, D.Sc., LL.D., F.R.S., Vice-President, in the Chair.

The following papers were read:

"Age Cycles and Other Periodicities in Organisms," by C. M. Child, Ph.D., Professor of Zoölogy, University of Chicago.
(Introduced by Prof. C. E. McClung.)

- "Coöperation as a Factor in Evolution," by William Patten, A.M., Ph.D., Professor of Zoölogy, Dartmouth College. (Introduced by Prof. H. H. Donaldson.)
- "On the Effects of Continued Administration of Certain Poisons to the Domestic Fowl, with Special Reference to the Progeny," by Raymond Pearl, A.B., Ph.D., Biologist, Maine Agricultural Experiment Station.
- "Types of Neuromuscular Mechanism in Sea-Anemones," by George H. Parker, Sc.D., Professor of Zoölogy, Harvard University.
- "Determination of Stellar Magnitudes by Photography," by Edward C. Pickering, Ph.D., D.Sc., LL.D., Director of the Observatory, Harvard University.
- "Monochromatic Photography of Jupiter, Saturn and the Moon" (illustrated by Color-Photographs made with the Mt. Wilson 60-inch telescope), by Robert Williams Wood, A.B., LL.D., Professor of Experimental Physics, Johns Hopkins University.
- "On the Eclipses of Jupiter's Satellites," by John Q. Stewart, B.S., of Princeton. (Introduced by Prof. H. N. Russell.)
- "On the Probable Temperature of Mars," by Henry Norris Russell, Ph.D., Professor of Astronomy, Princeton University.
- "A New Catalogue of Variable Stars," by Annie J. Cannon, A.M. (Introduced by Prof. E. C. Pickering.)
- "Legal and Political International Questions and the Recurrence of War," by Thomas Willing Balch, A.B., LL.B., of Philadelphia.

Afternoon Session—2 o'clock.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

Symposium on International Law: Its Foundation, Obligation and Future.

Outline,

by Hon. John Bassett Moore, LL.D., Member of the Permanent Court at the Hague, late Assistant Secretary of State.

Judicial Aspects: International Arbitration,
by Hon. Charlemagne Tower, A.B., LL.D., late Ambassador
to Germany.

Legislative Aspects,

by George Grafton Wilson, A.M., Ph.D., LL.D., Professor of
International Law, Harvard University. (Introduced by
Hon. John Bassett Moore.)

Administrative Aspects,

by Philip Marshall Brown, A.M., Professor of International
Law, Princeton University. (Introduced by Hon. Charle-
magne Tower.)

World Organization,

by Hon. David Jayne Hill, A.M., LL.D., Member of Perma-
nent Administrative Council of the Hague Tribunal, Late
Ambassador to Germany.

The following paper was read:

"The Isles of the Blest,"

by Paul Haupt, Ph.D., LL.D., Professor of Semitic Philol-
ogy, Johns Hopkins University.

Stated Meeting May 5, 1916.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

Messrs. W. W. Atterbury, and Eli K. Price, Jr., newly elected
members, subscribed the Laws and were admitted into the Society.

Letters accepting membership were received from:

William Wallace Atterbury, A.M., Radnor, Pa.

Maxime Bôcher, A.B., Ph.D., Cambridge, Mass.

Percy Williams Bridgman, Ph.D., Cambridge, Mass.

James Mason Crafts, S.B., LL.D., Boston, Mass.

Henry Platt Cushing, Cleveland, Ohio.

Edward Murray East, M.S., Ph.D., Boston, Mass.

Frank Rattray Lillie, Ph.D., Chicago, Ill.

William E. Lingelbach, A.B., Ph.D., Philadelphia.

Daniel Trembly MacDougal, A.M., Ph.D., Tucson, Ariz.

Charles Frederick Marvin, M.E., Washington, D. C.

Lafayette Benedict Mendel, A.B., Ph.D., Sc.D., New Haven, Conn.

Forest Ray Moulton, Ph.D., Chicago, Ill.

Eli KirkPrice, A.B., LL.B., Philadelphia.

William Morton Wheeler, Ph.D., Boston, Mass.

Frank Dawson Adams, D.Sc., Ph.D., F.R.S., Montreal

Prof. John B. Watson, of Baltimore, read a paper on "The Homing Problem in Birds."

Stated Meeting October 6, 1916.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

Dr. William E. Lingelbach, a newly elected member, subscribed the Laws and was admitted into the Society.

Acceptances of election to membership were received from:

Erwin F. Smith, Sc.D.,	Washington, D. C.
Joannes Diderick van der Waals, Ph.D.,	Amsterdam.
Wilhelm L. Johanssen, M.D., Ph.D.,	Copenhagen.

The decease was announced of

Silvanus Phillips Thompson, D.Sc., LL.D., at West Hampstead, London, on June 12, 1916, æt. 65.

Prof. Gaston Camille Maspero, at Paris, on June 30, 1916, æt. 70.

Sir William Ramsay, K.C.B., F.R.S., on July 23, 1916, æt. 64.

Hon. Samuel Whitaker Pennypacker, at Schwenksville, Pa., on September 2, 1916, æt. 73.

Josiah Royce, Ph.D., LL.D., at Cambridge, Mass., on September 14, 1916, æt. 60.

Hon. Seth Low, at Bedford Hills, N. Y., on September 17, 1916, æt. 66.

Dr. A. Parker Hitchens read a paper entitled "The Etiology and Pathogenesis of Hay Fever as Related to our Present Knowledge of Anaphylaxis" which was discussed by Dr. Macfarlane, Dr. Davis, Prof. McFarland and others.

On motion the following was unanimously adopted:

"WHEREAS an effort is being made to bring into co-operation existing governmental, educational, industrial, and other research organizations with the object of encouraging the investigation of natural phenomena, the application of scientific principles in American industries, the employment of science in the national defense, and such other objects as will promote the national welfare, and

"WHEREAS these objects are among those for which the American Philosophical Society exists,

"Now *therefore*, be it resolved that The American Philosophical Society hereby registers its approval of the co-ordination and federation of the research agencies of the country and expresses its willingness to join with and assist the National Research Council, organized by the National Academy of Sciences to accomplish the above federation."

Stated Meeting November 3, 1916.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

The decease of the following members was announced:

James Morgan Hart, A.M., at Washington, D. C., on April 18, 1916, æt. 77.

Theodore Newell Ely, C.E., on October 28, 1916, æt. 70.

The following papers were read:

"Obituary notice of Prof. Frederick W. Putnam," by Mrs. Cornelius Stevenson.

"Obituary Notice of Prof. Gaston Maspero," by Dr. Morris Jastrow, Jr.

"Conservation of Horses in War," by Dr. C. J. Marshall.

Stated Meeting December 1, 1916.

WILLIAM W. KEEN, M.D., LL.D., President, in the Chair.

The decease was announced of:

Cleveland Abbe, A.M., S.B., Ph.D., at Chevy Chase, Washington, D. C., on October 28, 1916, æt. 78.

Percival Lowell, A.B., LL.D., at Flagstaff, Arizona, on November 12, 1916, æt. 61.

Mr. Hampton L. Carson read an "Obituary notice of Samuel Dickson, Esq."

Mr. W. L. Stevenson read a paper on "The Sewage Disposal Problem Confronting the City of Philadelphia," which was discussed by Dr. A. C. Abbott, Dr. W. P. Wilson and Dr. Keen.

Dr. Keen presented the Annual Address of the President.

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